A MARINE SYSTEMATIC CONSERVATION PLAN FOR RODRIGUES ISLAND, WESTERN INDIAN OCEAN

Charles Olivier Arvin Pasnin

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Marine Research Ma-Re Institute and Zoology Department
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Supervisor: Assoc. Prof. Colin Attwood

Table of Contents

Contents

List of Tables iv

List of figures v

List of Appendices v

Acknowledgements viii

List of abbreviations ix

Chapter 1: General Introduction to a Marine Systematic Conservation Plan for Rodrigues Island 2

1.1 Introduction 2

1.2 The Marine Environment of Rodrigues 2

1.3 History of fishing in Rodrigues 4

1.3.1 The fishing Industry in Rodrigues 4

1.4 Marine reserves 8

1.4.1 Marine Reserves of Rodrigues 10

1.5 Conservation Planning in the Marine Environment 14

Chapter 2 16

Abstract 16

2.1 Introduction 17

2.2 Methodology 19

2.2.1 Data source for biotopes 19

2.2.2 Data Source for the seine net fishery 20

2.2.3 Non-metric Multi-dimensional Scaling & Cluster Analysis 21

2.2.4 Marxan 21

2. 2.5 Preparing input files for Marxan 23

2.2.5.1 Input parameter file 23

2.2.5.2 Planning Unit file 23

2.2.5.3 Conservation feature file 24

2.2.5.4 Planning Unit versus Conservation Feature file 24

2.2.5.5 Boundary length file 25

2.3 Results 26

2.3.1 Similarity in biotopes among planning units 26

2.3.2 Similarity of species composition in catches among planning units 29

2.3.3 Linking the seine net fisheries data to the biotopes 33

2.3.4 Biotope data 34

2.3.5 Seine Net Fisheries data 35

2.3.6 Biotope and Seine Net Fisheries data 36

2.3.6.1 Calibration of Species Penalty Factor 37

2.3.6.2 Locking in planning units containing marine reserves 38

2.4 Discussion 39

2.4.1 Biotope 39

2.4.1.1 Cluster Analysis 39

2.4.1.2 Marxan Analysis 40

2.4.2 Seine net fishery 40

2.4.2.1 Cluster Analysis 41

2.4.2.1 Marxan 42

2.4.3 Biotope & seine net fishery 42

2.4.3.1 Marxan analysis 43

2.4.4 Assessing the established marine reserves 43

2.4.4.1 Anse Aux Anglais marine reserve 44

2.4.4.2 Riviere Banane marine reserve 45

2.4.4.3 Passe Demie marine reserve 45

2.4.4.4 Grand Bassin marine reserve 46

2.4.5 Which approach to use? 47

Chapter 3 50

Recommendations 50

Conclusions 51

References 53

Appendices 60

List of Tables

Table 1: Number of registered fishermen on Rodrigues Island from 2002-2008 5

Table 2: Export of fish to Mauritius from 1999-2008 7

Table 3: Fish caught on Rodrigues Island from 2002-2008 7

Table 4: Location of the four marine reserves in the north of Rodrigues 13

Table 5: Planning unit status... 23

Table 6: Listing of PUs and biotopes for each cluster identified at 50% Bray Curtis similarity based on biotopes... 28

Table 7: Listing of PUs and fish species for each cluster identified at 50% Bray Curtis similarity based on fish catch 31

Table 8: Combinations of the 26 abiotic variables (biotope), taken k at a time, yielding the best matches of biotic and abiotic similarity matrices for each k 33

List of figures

Figure 1: Seine net fishers 5

Figure 2: Location of existing MPAs and proposed MPAs in Rodrigues 10

Figure 3: Boundaries of SEMPA 11

Figure 4: Location of four marine reserves 13

Figure 5: Benthic biotopes (Chapman, 2004) 19

Figure 6: Location of seine net fishing data sites (2002 – 2009) 20

Figure 7: Cluster diagram showing similarity in biotopes among planning units 27

Figure 8: Cluster diagram showing similarity in species composition in catches among planning units 30

Figure 9: Planning units targeted using only biotope data 34

Figure 10: Planning units targeted using only seine net fisheries data 35

Figure 11: Planning units targeted using biotope & seine net fisheries data 36

Figure 12: Targeted planning units when SPF is calibrated 37

Figure 13: Targeted planning units when marine reserves are locked in 38

List of Appendices

Appendix 1: Similarity between planning unit based on species composition in catches 60

Appendix 2: Similarity between planning unit based on biotope classification 60

Appendix 3: Seine net fishing sites within different biotopes 61

Appendix 4: Input parameter file 61

Appendix 5: SPF of conservation features for biotope data 62

Appendix 6: SPF of conservation features for seine net fishing data 63

Appendix 7: SPF of all conservation features for biotope and seine net fishing 66

Appendix 8: Habitat and feeding information for 12 most fished species 70

Appendix 9: List of all fish species & catch from 2002 to 2009 71

Appendix 10: Types of fishing activities in Rodrigues 74

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List of abbreviations

MPA	Marine protected areas
GIS	Geographical Information System
SEMPA	South East Marine Protected Area
IUCN	International Union for Conservation of Nature
BLM	Boundary length modifier
PU	Planning Unit
CBD	Convention on biological diversity

Chapter ONE

Chapter 1: General Introduction to a Marine Systematic Conservation Plan for Rodrigues Island

1.1 Introduction

Often referenced as the Cinderella of the Mascarene Islands; Rodrigues (19’4”S, 63’25”E) is situated in the inter-tropical zone of the South Western Indian Ocean at about 900 km east of Madagascar and is the largest offshore platform along the East African coast (Schils *et al.*, 2004). Being of volcanic origin, Rodrigues is the youngest (about 1.5 million years) and smallest of the Mascarene Islands with a surface area of 104 km^2; however it has the largest reef lagoon in the Indian Ocean (Bunce *et al.,* 2008) which is 13 km wide and 240 km^2 (Heemstra *et al.,* 2004).

The island is semi-autonomous since 2001 and comprises a total population of 37,700 (2008 national census). Rodrigues is less developed than its central government in the main island of the Republic of Mauritius; which has flourished as a result of the sugar industry and expansion of the tourist industry (Bunce *et al*., 2009). Rodrigues Island has been heavily deforested for agriculture in the early 1800s leading to severe erosion problems (Winton, 2006).

1.2 The Marine Environment of Rodrigues

Rodrigues is surrounded by a fringing reef which is nearly continuous around the island covering a total area of approximately 230.6 km^2 with no continental shelf (Turner & Klaus, 2005). The lagoon flushes completely in four to seven days (Turner *et al*., 2000) aided by three major tunnels and small passes in the reef (Winton, 2006). The tidal range within the lagoon is a maximum of 1.5 m (Hardman *et al.,* 2006a). GIS mapping of biotopes revealed that the lagoon is dominated by sand (40 %), vegetation which is mainly sea grass and macro-algae (28%) and lagoon corals (21%) (Chapman & Turner, 2004).

The first biodiversity workshop held during the Shoals of Capricorn Program in 2001 (Oliver & Lynch, 2004) documented 130 species in 40 genera of hard corals along with eight unidentified species (Fenner *et al*., 2004); 493 species of fish, nine representing undescribed (new) fish species (Heemstra *et al*., 2004); 74 species of echinoderm with 10 new records for the Mascarene islands (Rowe & Richmond, 2004); and 109 species of bivalve (Oliver *et al.*, 2004). There could be 600 coastal fish species, and a total of 1000 species when including pelagic and deepwater fish (Bunce *et al.*, 2008). Several fish species not recorded by Heemstra *et al.* (2004) have been recorded by Shoals Rodrigues surveyors during the course of their on-going fish monitoring activities (Anderson, 2006), particularly of the seine net fishery (Lynch *et al.*, 2003-2005). No studies have been done on cetaceans around the island, which comprise mainly whales and dolphins (Anderson, 2006).

Corals of Rodrigues Island have been referred to on several occasions as being the most pristine in the Western Indian Ocean with greatest coral species richness found on the reef slopes (Fenner *et al*., 2004). The reefs of the island consist mainly of *scleractinian* corals, with *Acropora* species dominant on both the reef flat and reef slope (Hardman *et al.*, 2006).

Coral degradation is easily observed on the reef flat areas, and this is largely caused by natural and anthropogenic impacts. Natural impacts include regular cyclones, 2-16 per year (Turner & Klaus, 2005), and more recently localised coral bleaching in some areas (Hardman *et al.,* 2004). Anthropogenic impacts have a much more destructive effect on corals and these include run-off water as a result of deforestation leading to increased sedimentation, effluent in groundwater and other discharges (Turner & Klaus, 2005), opencast and coral sand mining, beach construction and small scale land reclamation (Chapman, 2000). However, the most destructive of the anthropogenic pressures remains reef fishing, with damage caused by anchoring, loss of gear, reef trampling, overturning of coral and use of poles to pound the reef in order to scare fish during seine net fishing (Chapman, 2000).

1.3 History of fishing in Rodrigues

Few scientific studies have been done to date on Rodrigues and only recently have scientists taken an interest in marine research; and then mostly on the extensive coral reefs surrounding the island (Oliver & Lynch, 2004). Historical records depict the lagoon of Rodrigues as being once abundant with fish and other marine animals. Sharks could be observed in the lagoon and tuna were abundant in the open sea (Oliver & Lynch, 2004). There was also a large market for turtles and tortoises which were abundant on the island (Bunce *et al.*, 2008). Dugongs were common and it is suspected that extensive sea-grass beds were present being their main food source (Oliver & Lynch, 2004). Today, sharks have disappeared from the lagoon, turtles are rarely observed and evidence of dugongs or sea-grass beds can only be found in literature.

Fishing in Rodrigues started in 1792 (Turner & Klaus, 2005) with catches of 150 to 200 fish at a time and many left as food for birds (Pingré, 1763). The turtle fishery was intensive in the mid-18th century with some 500 to 600 individuals taken annually (North-Coombes, 1971). There was also a large market for tortoises which were eventually eradicated from the island. They were esteemed for their meat particularly because they could be kept alive on boats providing food for long voyages at sea. Historically fishing activities in Rodrigues were linked with market demands in Mauritius and fishing at an unsustainable rate may have started in the early 1800s (Bunce *et al.*, 2008).

1.3.1 The fishing Industry in Rodrigues

The fishing industry is one of the largest employment sectors in Rodrigues especially since there is a lack of industrial development. The region is semi-arid thus leading to limited agricultural activities and tourism is only now developing. There were 1,891 full-time registered fishers in 2008 which makes up nearly 11% of the workforce and about 2000 people fishing on a recreational basis (Kaly *et al.*, 2007). Fishing takes place almost entirely in the lagoon as there is a lack of suitable boats strong enough to withstand the south east trade winds outside the lagoon and particularly in winter.

Table 1: Number of registered fishermen on Rodrigues Island from 2002-2008 (Digest of statistics on Rodrigues, 2008)

Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Number of registered fishing boats	1,368	1,457	1,577	1,654	1,714	1,728	1,748
Registered fishermen	1,985	1,996	1,971	1,978	2,024	1,981	1,891
Professional fisherwomen	786	778	771	758	747	730	714
Fishermen (large net)	97	72	71	67	64	61	51
Fishermen (other)	1,102	1,146	1,129	1,153	1,213	1,190	1,126

From table 1, professional fisherwomen are registered fisherwomen who practice octopus fishing, fishermen (large net) are those who practice seine net fishing and the fishermen (other) are those who practice line and/or basket trap fishing. The registered fishermen comprised professional fisherwomen, fishermen large net and other, and they are those who have a permit to fish and thus will obtain a bad weather allowance when they are not able to fish due to bad climatic conditions.

The main types of fishing activities taking place inside the lagoon are seine netting, basket trapping, line fishing and octopus fishing (Appendix 11). Catches consist mainly of octopus, snapper, triggerfish, parrotfish, grouper, shrimp and crab from the lagoon and reef edge (Turner *et al.,* 2000).

Figure 1: Seine net fishers

Seine net catches have decreased from 264 tonnes in 1994 to 156 tonnes in 1997. A net buy-back scheme was introduced in 1997 as a management action and catch rates increased to 278 tonnes but fell again in 2005 to 188 tonnes (Fisheries Research and Training Unit, unpublished report). Moreover, total lagoon fish catches decreased from 1,240 tonnes in 1999 to 564 tonnes in 2005, but increases to 1, 078 tonnes in 2008. The CPUE within the seine net fishery has also declined significantly and the catch is now dominated by herbivorous species, while carnivorous fish are rare (Blais, unpublished). Studies have uncovered shifting baselines in fisher's perception of Rodrigues' fishery showing that large predators including groupers and sharks have been depleted indicating the demise of the fishery and an overall imbalance of the ecosystem (Bunce *et al.*, 2008).

Octopus fishing is of great importance in Rodrigues where *Octopus cyanea* accounts for 95% of the octopus species caught in the lagoon (Genave, 2000). The types of fishing gear used for this activity are mainly spears and harpoons. Octopus catches inside the lagoon have decreased from 382 tonnes in 2002 to 281 tonnes in 2008 (Table 3). The demand for octopus from Mauritius is relatively high and depletion of the octopus stock may be due to habitat loss from intensive trampling, a high incidence of coral overturning or breakage and overfishing (Genave, 2000). Alternative fishing techniques such as pot fishing was implemented on a small scale but proved unsuccessful, and options of exploring alternative livelihood means are minimal. There are insufficient funds available to develop new and efficient fishing techniques (Jacob, 2005). Moreover, the introduction of a bad weather allowance in the 1980's has contributed to an increase in fishing effort (Bunce *et al.,* 2009). To obtain this allowance fishers are required to fish at least half of the good weather days. Fishers, particularly fisherwomen, go fishing only to ensure that they can have their attendance marked thus resulting in an increase in fishing effort with catches being very low to none. Moreover, they are encouraged by the bad weather allowance scheme to fish on coral reefs thereby destroying the habitat and obtaining low catches (Jacob, 2005).

Table 2: Export of fish to Mauritius from 1999-2008. (Digest of statistics on Rodrigues, 2008)

Commodity Unit	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Salted fish/kg	n.a	100	40	230	2,255	1,465	695	870	913	1,756
Frozen fish/kg	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1,170	300	325
Dry octopus/kg	n.a	n.a	145	n.a	240	4,507	8,495	9,120	7,865	9,026
Frozen octopus/ tonnes	141	188	162	145	175	191	244	124	179	143
Sea cucumber/ tonnes	n.a	n.a	n.a	n.a	n.a	n.a	n.a	28	40	18

Table 3: Fish caught on Rodrigues Island from 2002-2008 (Digest of statistics on Rodrigues, 2008)

Fish in metric tonnes/ Year		2002	2003	2004	2005	2006	2007	2008
i) Lagoon	a) Octopus	382.8	580.2	323.8	285.0	266.4	254.1	281.3
	b) Other fish	840.7	948.9	836.3	563.6	640.7	886.1	1,078.1
i) Off lagoon		180.5	142.4	44.2	191.3	160.3	383.7	398.2
Total		1,404.0	1,671.5	1,204.3	1,039.9	1,067.4	1,523.9	1,757.6

The management methods so far introduced include the prohibition of spear fishing, reduction of large net licenses, enforcing a minimum mesh size of 9 cm and closing the large net fishing season between March and October (Hardman *et al.*, 2007). However, law enforcement is a problem in Rodrigues and poaching is a common practice. As a result other possible regulations or measures were proposed; such as marine reserves.

1.4 Marine reserves

A widely accepted definition for a marine protected area (MPA): “Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” (IUCN, 2010). The protected area can be a ‘no take’ zone or more flexible and allow other types of activities including fishing and diving under specific conditions.

MPAs have proved to be successful in many countries, particular when areas of sensitive habitats such as corals reefs are protected and also in areas where protection is needed from physical destruction by fishing gear (Attwood *et al.*, 1997). Attwood *et al*. (1997) described the major functions of MPAs, as follows:

- Protection of marine habitats

  Often considered as being indestructible, the marine environment is being more and more affected by anthropogenic impacts. MPAs provide protection for sensitive habitats but also control activities such as fishing and development which threaten biodiversity in estuaries and the sea.

- Conservation of genetic diversity

  Fisheries generally select large fish, causing selection for slow growth (Conover *et al.*, 2005; Law, 2007). Genetic variability and stability can be sustained by protecting certain individuals in an area from being overfished (Murawski, 2000). The maintenance of genetic diversity is important as fisheries require larger, healthier fish, particularly large females for higher recruitment success (Berkeley *et al.*, 2004).

- Conservation of species

  The conservation of species is a strong motivation to set up an MPA. Long ago, the sea was viewed as a limitless resource and fish stocks were thought to be inexhaustible with no concern for any species going extinct. There are a few endemic fish species which are globally extinct; but one of the few examples is the ‘green wrasse’ from Mauritius which went extinct in 1839 due to habitat destruction and pollution (del Monte Luna et al., 2007). It has been shown that fishing can have an effect on the composition of target and non target species and it was recommended that these effects must be taken into consideration when planning conservation areas (Halpern, 2003). The study also clearly showed evidence for increased species diversity inside protected areas.

- Fishery management

The use of MPAs as a tool to promote fisheries management is an important issue however there are still debates on its usefulness and particularly its effect on local communities. The use of marine reserves as a fishery management tool can be beneficial for multi species fisheries or sedentary stocks (Dalton, 2010) however it has less advantage for mobile species (Hilborn *et al.*, 2004). For instance, benthic marine reserves have shown to be successful in the Philippines, particular where an appropriate management approach has been used (Christie *et al.*, 2007), however there are very few oceanic marine reserves protecting mobile, pelagic species (Game *et al.*, 2009).

- Research

MPAs can provide benchmark areas for comparative research e.g. to compare areas impacted by fishing with no-take zones, as well as control sites for research studies.
MPAs can play a precautionary protective role when there are insufficient data available to support conventional fishery management approaches (Jones, 2007). MPAs also provide opportunity to promote marine education and build a sense of ownership among local people, thus raising their awareness of conservation.

- Other

Moreover, MPAs can provide an economic income in some countries with the promotion of ecotourism where tourists are charged to dive in or to visit marine reserves (Roncin *et al.*, 2008).

1.4.1 Marine Reserves of Rodrigues

Mauritius, as well as Rodrigues, are party to the CBD convention and have agreed to protect at least 20-30% of the marine environment under their jurisdiction by 2012. This target has now been reduced to 10% as only 1% of the world's marine waters are protected in MPAs (MPA news, 2010).

In 1984, Rodrigues had seven existing MPAs (Fig 2), five fishing reserves and two nature reserves, covering a total area of 15.8 km^2; which covers 6.5% of the lagoon (Foster, 2002). The MPAs were declared under the Fisheries Act No 75 of 1984 to prevent only seine net fishing in those areas with the main objective of increasing fish stocks. However, it has been reported that the MPAs are poorly enforced and illegal fishing is a common practice, with the exception of the two islets of Ile Aux Sable and Ile Aux Coco (nature reserves), both patrolled on a regular basis and where permits are required by visitors (Foster, 2002). Using GIS, Chapman and Turner (2004) showed that the MPAs were heavily impacted with three of the coastal reserves identified as lagoon mud, possibly from heavy sedimentation.

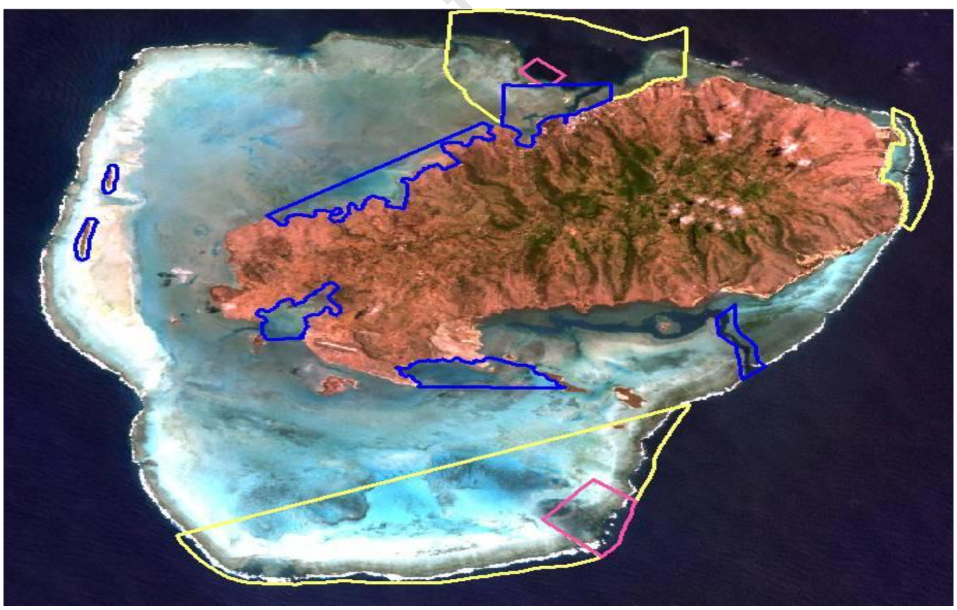

Figure 2: Location of existing MPAs in Rodrigues (blue boundaries), proposed MPAs (yellow boundaries) and proposed core areas (pink boundaries). Image from Chapman and Turner (2004).

Four marine reserves (no take zones) have been gazetted in the northern part of Rodrigues in April 2007 and one large MPA, South East Marine Protected Area (SEMPA), is proposed under a United Nations Development Project in the south part of the island covering both marine and terrestrial environments. The MPA (SEMPA) is the largest marine park of the Republic of Mauritius with an area of 43 km^2 (Fig. 3). The UNDP-GEF funded project, known as 'Partnerships for Marine Protected Areas in Mauritius and Rodrigues', is designed to create sustainable fisheries and make use of the benefits from Marine Protected Areas (MPA) through broad based stakeholder participation. The project will allow the development of policies, institutional frameworks and co-management arrangements for an MPA in Rodrigues.

The specific objectives of the SEMPA are to:

(i) Develop an enabling policy and institutional framework for sustainably co-managed MPAs throughout the Republic of Mauritius and;

(ii) Develop innovative co-management arrangements for MPAs and adapt them at a representative demonstration site in Rodrigues.

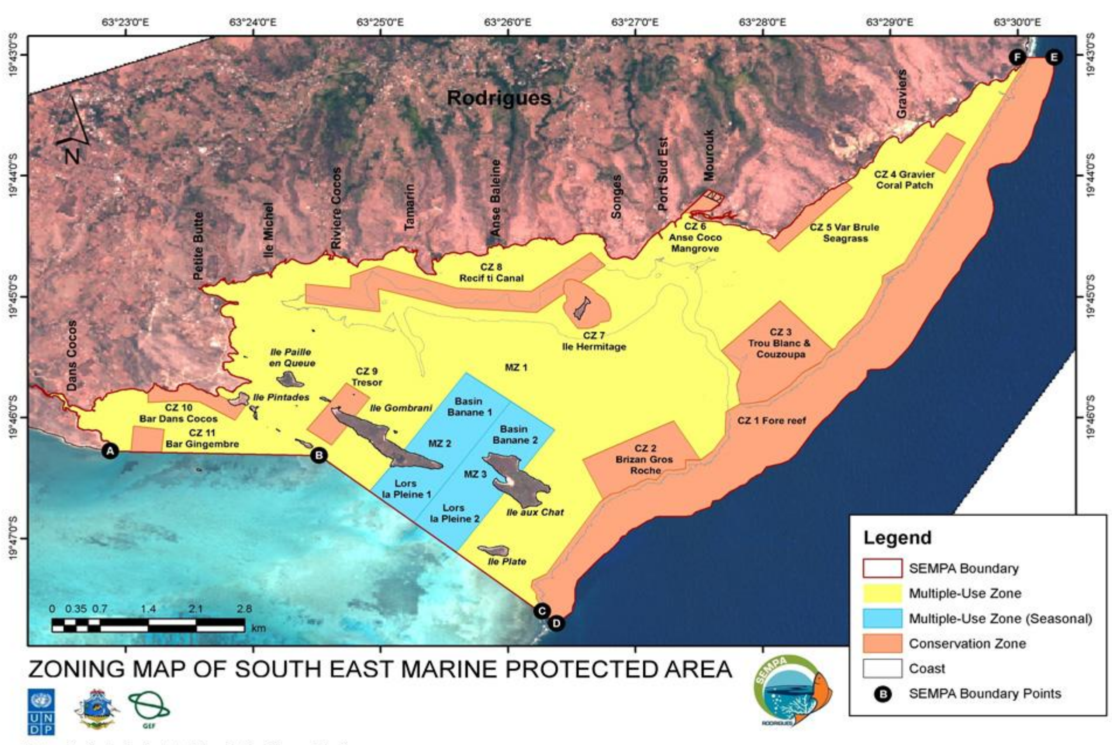

Figure 3: Boundaries of SEMPA. Image from http://www.sempa-rodrigues.com/index.php?id=4

The marine reserves in Rodrigues were established with the help of a local NGO called Shoals Rodrigues which was established in 2001. The main objectives of the marine reserves are to promote sustainable fisheries and to improve conservation of the marine environment. The creation of a network of marine reserves was decided by holding meetings in 17 fishing villages to obtain input from fishermen on the most appropriate marine reserves as well as their location.

In the past there has been a general lack of a conservation or sustainability culture in Rodrigues as the local community including fishermen believed that the sea could be exploited without restrain since it belongs to everyone (Gade, 1985) - a classic case of “the tragedy of the commons”. However, more recently the opposite belief was demonstrated in meetings held with fishermen as they agreed that their fisheries are in serious decline and that alternatives are needed (Hardman et al., 2007, 2008) with 86% of fishermen in favour of marine reserves (Gell *et al.,* 2003).

After the meetings, a shortlist of five possible marine reserves were decided based on areas needing protection from further degradation , possible spawning sites, areas with high fish abundance and pristine coral . A geographical information system of the Rodrigues lagoon was done (Chapman & Turner, 2004) to ensure that the reserves contained a range of different habitats and species; and four reserves were finally decided on (Fig. 4). Research activities have focused on setting up biological and socio-economic monitoring programs to assess the success of these reserves. Shoals Rodrigues aims to ensure that local stakeholders are included in decision-making through annual stakeholder meetings held at the different fishing villages. Fishers are updated on the progress of the reserves and consulted on issues such as enforcement and alternative livelihood options. The results of these meetings and the production of annual reports that include results on coral reef monitoring, the seine net fishery, benthos, reef fish and invertebrates are then relayed to the Rodrigues Regional Assembly through the Coordinating Committee for Fisheries and Marine Resources.

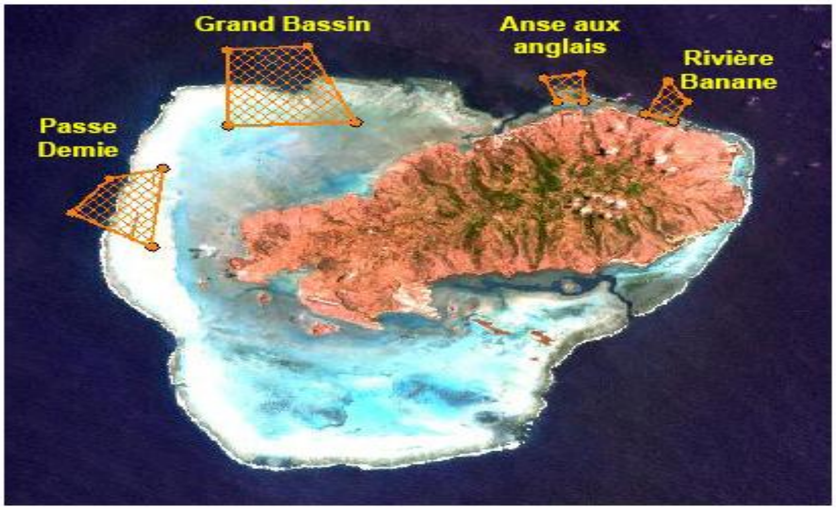

Figure 4: Location of four marine reserves

Table 4: Location of the four marine reserves in the north of Rodrigues

Name of MPA	**Location of the four corners**	**Size**
Riviere Banane	A: 19°39.936'S 63°28.874'E B: 19°39.328'S 63°28.500'E C: 19°40.473'S 63°28.628'E D: 19°40.257'S 63°28.085'E	Area: 1.5km^2 Perimeter: 5.3km
Anse Aux Anglais	A: 19°39.286'S 63°26.040'E B: 19°39.136'S 63°26.821'E C: 19°39.932'S 63°26.343'E D:19°39.904'S 63°26.858'E	Area: 1.5km^2 Perimeter: 5.0km
Grand Bassin	A: 19°38.401'S 63°21.372'E B: 19°38.505'S 63°19.777'E C: 19°40.589'S 63°19.827'E D:19°40.485'S 63°22.340'E	Area: 14.1km^2 Perimeter: 15.3km
Passe Demie	A: 19°42.072'S 63°17.471'E B:19°43.037'S 63°16.721'E C: 19°41.814'S 63°18.521'E D: 19°43.995'S63°18.292'E	Area: 7.2km^2 Perimeter: 11.4km

Source: www.shoals-rodrigues.org

With the four marine reserves covering a total area of 24.3 km^2 and SEMPA covering an area of 43 km^2, about 28% of the lagoon is under protection.

1.5 Conservation Planning in the Marine Environment

Conservation planning computational methods allow for the selection of reserves to maximize the representation of regional biodiversity. The use of conservation planning in the terrestrial environment is globally accepted and has proved to be successful in many countries (Carr *et al.*, 2003). However, uptake of this approach has been less fervent in the marine environment. Marine and terrestrial environments differ on many levels, most specifically due to the three-dimensional medium of the marine realm (Carr *et al.*, 2003). Conservation planning is inherently dependent on spatial data and adequate data on features such as biotopes, ecosystems and processes have also been elusive for the marine environment. This process is widely used in reserve design and provides a transparent and defensible selection based on clearly defined objectives (Pressey *et al.,* 2007). An example of marine systematic conservation planning is in the Prince Edwards Islands where Lombard *et al*. (2007) designed a MPA that protects biodiversity patterns and also minimizes conflict with the Pantagonian toothfish fishery.

Comprehensiveness and transparency in reserve design ensures that stakeholders and other interested and affected parties are involved in planning from the inception and can easily understand the objectives, decision making procedures and outputs. Thus, they are more willing to participate and buy-into the process. A good basis for a systematic approach is to use sound data and provide transparent reporting on the progress of achieving objectives. Both conservation and socio-economic considerations can be accounted for and the ability of a particular configuration to attain those objectives are assessed and reported on.

Chapter TWO

Chapter 2

Abstract

In 2007 the local government of Rodrigues gazetted four marine reserves in the north of the island based on knowledge and insights from stakeholders, mainly from the fishing community. In order to verify the stakeholder-based design, a marine reserve network was designed using Marxan, a systematic conservation planning programme. The aim was to design a marine protected area network for Rodrigues using available spatial data on biotopes and fish catches to achieve fisheries benefits and marine biodiversity protection. These two data sets complement each other. The biotope survey was done by Chapman & Turner (2004),a Landsat 7 ETM+ satellite image was obtained to guide survey work and for mapping of the biotopes and survey data were used to ground-truth the satellite image and develop a biotope map of the lagoon. The fish catch data was obtained from Shoals Rodrigues, a local NGO. The staff followed seine net fishers during the course of a fishing day and all species being fished were transferred to the survey boat where the number of individual fish per species was recorded as well as the GPS position. A cluster analysis was done using Primer 6 to observe the distribution of all conservation features, 26 biotopes and 118 fish species, across the planning units. The results showed that the conservation features were well distributed inside the lagoon. Marxan was run separately with the biotope data first and then using only catch data, then both together. All parameters were set to default and the Species Penalty Factor was calibrated. The results showed that the marine reserves designed using local stakeholder's knowledge fell into the selected areas designed by Marxan. The south part of the lagoon was also selected in the reserve design, close to land where an MPA (SEMPA) is under construction and also further out where there is no protection. The results from the analyses can be used to inform decisions by providing a set of options that should protect the full range of biodiversity in the island waters.

2.1 Introduction

The fishing industry is of great economic importance in Rodrigues Island since agriculture has not flourished due to dry conditions and frequent cyclones, and tourism is still in its infancy. Rodrigues was described as an island of resources, with tortoises covering the beaches, dugongs living on the sea grass habitat, turtles and sharks in the lagoon and an abundance of fish (Oliver & Lynch, 2004; Bunce *et al.*, 2008). One common example of the rapid degradation of the island's biodiversity is the extinction of the island's emblematic bird the Solitaire (*Pezophaps solitaria*) during early settlements since this ground bird was favored for its meat. It is generally accepted that land degradation is closely linked to degradation of the associated marine environment (Bunce *et al.*, 2008).

The main types of fishing activities occurring around the island are hook and line, octopus, basket trap and seine net fishing; which occur mainly within the lagoon. The management methods introduced so far is the prohibition of spear fishing, reducing the number of licenses for large net fishing, enforcing a minimum mesh size of 9 cm and closing the large net fishing season between March and October.

The use of Marine Protected Areas in protecting natural habitats and fish stocks is established in many parts of the tropics. By 2002 Rodrigues had seven MPAs declared covering a total area of 15.8 km^2 (Foster, 2002) which covered about 7% of the lagoon. The MPAs were declared under the Fisheries Act No 75 of 1984 to prevent seine net fishing while allowing all other types of fishing however, it has been reported that they are not well enforced and seine net fishing continues illegally. Trampling from octopus fishing continues to damages coral reefs.

It has been reported that total lagoon catches have declined by 50% between 1998 and 2006, and octopus catches by 775 tons in 1994 to 266 tons in 2006 (Fisheries Research & Training Unit, unpublished data). The catch per unit effort of the seine net fishery also declined significantly over the past five years with the catch now dominated by small herbivorous fish, whereas carnivorous are rare. Important species are being harvested often before they reach maturity. It has also been reported that there is a lack of law enforcement resulting in seine net fishers using illegally small mesh sizes and collecting juvenile fish (Blais, unpublished).

As a result of the decline in fisheries and the deterioration of coral and algal habitat from fishing activities, the local government of Rodrigues has gazetted four marine reserves (no take zones) in the north of the island in 2007 which cover approximately 24.3 km^2 (Hardman *et al.*, 2010) about 10% of the lagoon. Moreover, the local government in collaboration with the United National Development Project is working on a large MPA in the south of the island to cover an area of 43 km^2. However, no management measures have been enforced so far and seine net, hook and line and basket trap fishing are still taking place within the designated marine reserves (Hardman *et al.*, 2010).

The aim of this project is to design a marine protected area network for Rodrigues using available spatially-referenced biotope and fisheries data to achieve comprehensive marine biodiversity protection. It is recognised that the existing MPAs, though designed on the basis of expert knowledge and stakeholder input, may not be the most efficient design to accomplish comprehensive protection of the island biodiversity. A Marxan analysis will be used to identify sets of possible reserve configurations to meet pre-determined targets and to compare these sets against the existing MPA designs.

2.2 Methodology

2.2.1 Data source for biotopes

The biotope survey was done by Chapman & Turner (2004). Snorkelling and SCUBA diving surveys were carried out at 183 sites selected on a random stratified distribution. This was done from June to August 2000 within the major apparent habitats of the lagoon and reef to identify marine biotopes. The central position of an area of 90 m x 90 m was recorded using a GPS at each site. A six-point SACFOR relative abundance scale, **S**uperabundant (76 to 100% cover or >100 individuals)=6, **A**bundant (51 to 75% cover or 51 to 100 individuals)=5, **C**ommon (31 to 50% or 21 to 50 individuals)=4; **F**requent (11 to 30%, or 11 to 20 individuals)=3; **O**ccasional (1 to 10% or 2 to 10 individuals)=2; **R**are (<1% or one individual)=1, was used to record the physical habitat characteristics, substratum composition, biological cover and macro-benthic species across the total area of each site. Forty two biotopes were recorded within 15 biotope groups in the four major habitats of coral, sand/rubble, lagoon mud and consolidated limestone. Mapping of the biotopes was hampered by spectral variability within one biotope (such as reef flat corals), and similarities between contrasting habitats (such as mud and coral patch reefs, or dense corals and seagrass). These were incorporated into GIS for spatial representation.

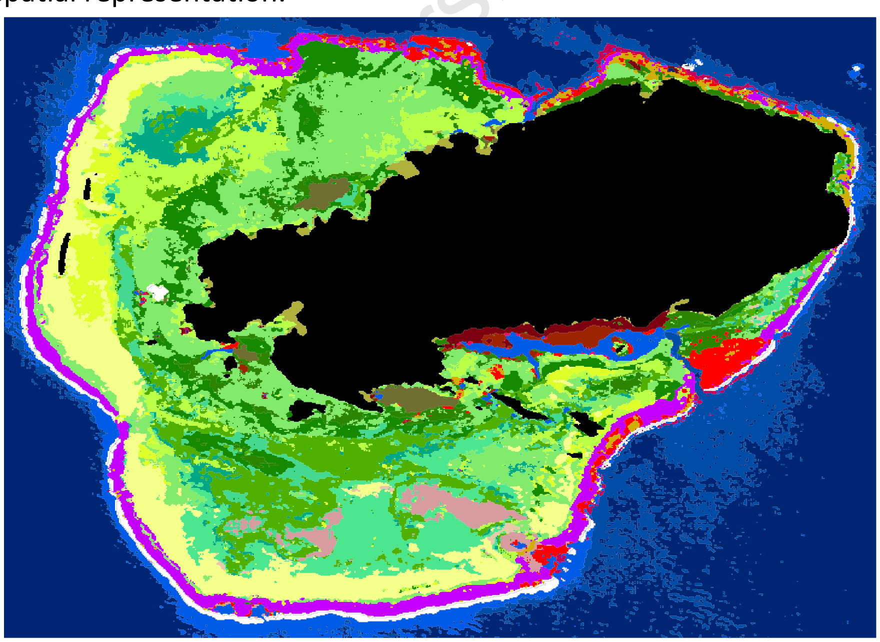

Figure 5: Benthic biotopes (Chapman, 2004)

2.2.2 Data Source for the seine net fishery

The seine net fishery data for this project were collected by staff of Shoals Rodrigues. This NGO has been undertaking marine research, training and educational programs since its establishment in 2001. As part of various monitoring schemes, Shoals Rodrigues began a seine net fishery monitoring program in 2002.

The first report on the seine net fishery was produced in 2002. Since then annual reports have been produced based on data recorded by Shoals Rodrigues and volunteers during the seine net open season - 1st March to 30th September. Fish caught during seine net fishing comprise 42% of the total lagoon catch. Staff of Shoals Rodrigues followed a seine net team during the course of a fishing day and recorded the GPS position and time of each haul (net deployment). All the fish that were caught were transferred to a survey boat, where the species and total length of each individual was determined. The number of sets was also recorded. Attempts were made to follow each team twice a month during the seine net open season. The number of surveys done annually varied depending on staff available. 126 different fish species were caught from 2002 to 2009 (Appendix 10), and only 118 fish species were used for the Marxan analysis as some of the less important commercial species were not properly spatially referenced.

Figure 6: Location of seine net fishing data sites (2002 – 2009)

2.2.3 Non-metric Multi-dimensional Scaling & Cluster Analysis

Multivariate analyses were done using Primer 6 (Clarke & Warwick, 2001) to analyse the similarity between planning units in relation to seine net catch and biotope data respectively. Abundance of catch and area of biotope per planning unit was used for the analysis. A Bray-Curtis similarity matrix, cluster analysis and multi-dimensional scaling (MDS) plots were generated on fourth root transformed data. The distribution of the conservation features across the planning units was observed. A SIMPER analysis was done on the Bray-Curtis similarity matrix to identify the percentage contribution of the conservation feature to each cluster of planning units (Clarke & Warwick, 2001).

A Bio-Env test was done to test the correlation between the seine net fisheries (biotic) and biotope datasets (abiotic) (Clarke & Warwick, 2001). A square root transformation was done on the biotic data (seine catch) followed by a Bray Curtis similarity. The abiotic variable (biotope abundance) was normalized and a Bio-Env analysis was then done to describe variation in fish species composition in relation to biotopes.

2.2.4 Marxan

C-Plan and Marxan are reserve selection software commonly used by conservation planners. Marxan was used for this project as it is more widely used for conservation planning in the marine environment (Watts et al., 2009). Marxan is a data-hungry tool which accommodates biological, physical or socio-economic spatial data. As long as data are spatially referenced, Marxan can analyze input features and propose target areas. Data quality is therefore important, and should be available for the entire planning domain.

Marxan calculates a minimum reserve set to minimize the cost of achieving defined targets. "Simulated annealing" is a site optimization algorithm used in Marxan to search for the combination of areas which will satisfy specified conditions. Each planning unit is examined for the values it contains in order to design an optimal reserve network by assigning a score based on the following equation:

Score = Cost + **Boundary length** of the reserve system + **Penalty** incurred for unmet targets

Marxan solves a type of problem described as the minimum-set problem; where the objective is to minimize cost subject to achieving defined targets.

Each solution proposed by Marxan is given a score based on how well it achieves the objective. The reserve system with the lowest score is the optimum design. Each planning unit is assigned a cost which the user decides based on the objectives. The cost can be calculated in different ways, for instance it can be the actual financial value of the site or actual area of the planning unit. The boundary length of the reserve system is the sum of the boundaries of selected planning units that share a boundary with planning units outside the reserve design. Connected planning units will have a lower boundary length. For each solution proposed by Marxan, the output shows if the target for each conservation feature is being met or not. For unmet targets, the species penalty factor (SPF) of that conservation feature can be increased so that Marxan gives more consideration for that target to be met in subsequent trials.

Two data sets were used for the Marxan analysis: a biotope classification of the lagoon done by Chapman & Turner (2004) and seine net catch data from 2002-2009. Marxan was initially run with a BLM of 0 and SPF of 1 for all conservation features. The BLM controls the level of compactness and clustering of the targeted areas while the SPF controls the level of penalty applied when a conservation feature target is not met. Only the SPF was calibrated for this project since the primary objective is to identify sites of high biodiversity value.

The biotope and seine net fisheries data were first run separately in Marxan before combining both datasets in the 3rd run. Planning units containing established marine reserves were locked in, thereby fixing these planning units in the reserve system, to determine differences with the reserve design proposed by Marxan in the 4th run. Results obtained from Marxan were displayed in ArcGIS 9.3.

2. 2.5 Preparing input files for Marxan

Marxan requires four input files in order to run; namely input parameter, planning unit, conservation feature and planning unit versus conservation feature files. The boundary file is optional.

2.2.5.1 Input parameter file

The input parameter file sets the values for all the main parameters required for Marxan to run. It is also used to indicate the location of the input and output files. The parameters were kept as default (Appendix 4).

2.2.5.2 Planning Unit file

The planning unit file is a list of planning units in the region of interest, each assigned with a unique identifier. It contains additional information such as the cost and status of each planning unit. The cost is the value given for adding each planning unit into the solution. The status indicates if the planning unit is locked or not in the reserve design. A status of 0 to 3 can be given to each planning unit as described in Table 5.

Table 5: Planning unit status

Status	Meaning
0	The PU is not guaranteed to be in the initial (or seed) reserve system, however, it still may be. Its chance of being included in the initial reserve system is determined by the ‘starting proportion’ specified in the Input Parameter File.
1	The PU will be included in the initial reserve system but may or may not be in the final solution.
2	The PU is fixed in the reserve system (“locked in”). It starts in the initial reserve system and cannot be removed.
3	The PU is fixed outside the reserve system (“locked out”). It is not included in the initial reserve system and cannot be added.

The size of each planning unit was determined by looking at the spatial distribution of available data. A size of 1 mile by 1 mile was used to design the planning units (polygons). These were constructed in ArcGIS 9.3 using the ET Geowizards extension (http://www.ian-ko.com/). Each conservation feature was observed carefully to ensure that they were well distributed in each planning unit. The smaller the planning unit the greater the resolution will be, however it is important to use datasets that complete coverage of the study region. The cost of each planning unit was set to one, effectively eliminating the cost from the objective function, which is a mathematical formulation of the minimum set problem. This allows for the selection of planning units based only on features. Marxan was run with a status of 0 for all planning units; and a run was also done with a status of 2 for already protected planning units.

2.2.5.3 Conservation feature file

The conservation feature file contains information on conservation features being considered. The conservation features used are fish species caught during seine net fishing (point data) and biotopes identified in the lagoon (polygon data). Each conservation feature was given a unique identifier. The target for each conservation feature was set at 20% according to the target set by IUCN to protect 20% to 30% of global biodiversity. The species penalty factor (SPF), which controls the level of penalty applied when a conservation target is not met, was set to one. Calibration of the SPF was done after the first run for targets which are not being met.

2.2.5.4 Planning Unit versus Conservation Feature file

This file contains information on the distribution of conservation features across planning units. Essentially it indicates in which planning unit a particular conservation feature is found along with the abundance or relative abundance of that given conservation feature. The abundance of each biotope in each planning unit was determined using the spatial location in ArcGIS 9.3, which creates a table join in which fields from one layer's attribute table are appended to another layer's attribute table based on the relative locations of the features in the two layers. For seine net fishing, the average number of fish caught for each species and fishing effort was determined by dividing the number of catch for each species by the number of sets. Then the fishing effort for each species per planning unit was calculated using spatial location in ArcGIS 9.3.

2.2.5.5 Boundary length file

The boundary length file contains information about the spatial relationship between planning units. The BLM is important to produce some level of 'clumping' or compactness. Targeted planning units which are closer or clump together are easier to manage and reduce edge effects.

2.3 Results

2.3.1 Similarity in biotopes among planning units

Twenty clusters of planning units were formed at 50% similarity on the basis of similarity in planning units which were grouped based on the similarity of the 26 biotopes. The three outliers on the left of Figure 7 are planning units which contain only intertidal sand and mud, and sparse vegetation. Table 6 below shows the different clusters formed, from left to right of Figure 7, and the planning units along with the key biotopes which contribute to each cluster formed, obtained from the SIMPER analysis. The average similarity between the planning units is also shown (Figure 7). Only key biotopes which contribute to each cluster formed are shown Table 6, whereas all biotopes found in clusters containing only one planning unit were shown.

At 12% similarity, two major clusters of planning units were formed with the left hand cluster containing mainly reef edge corals, channels/shallow coastal and deep coastal water. These are planning units which are found close to the coral barrier. The second cluster found to the right of the diagram grouped planning units which are found mainly in the lagoon thus containing vegetation as the main biotopes.

At 50% similarity, clusters 'b' to 'l' contained planning units which are found close to the coral reef barrier and deep ocean; whereas clusters 'k' to 't' contained planning units which are found inside the lagoon.

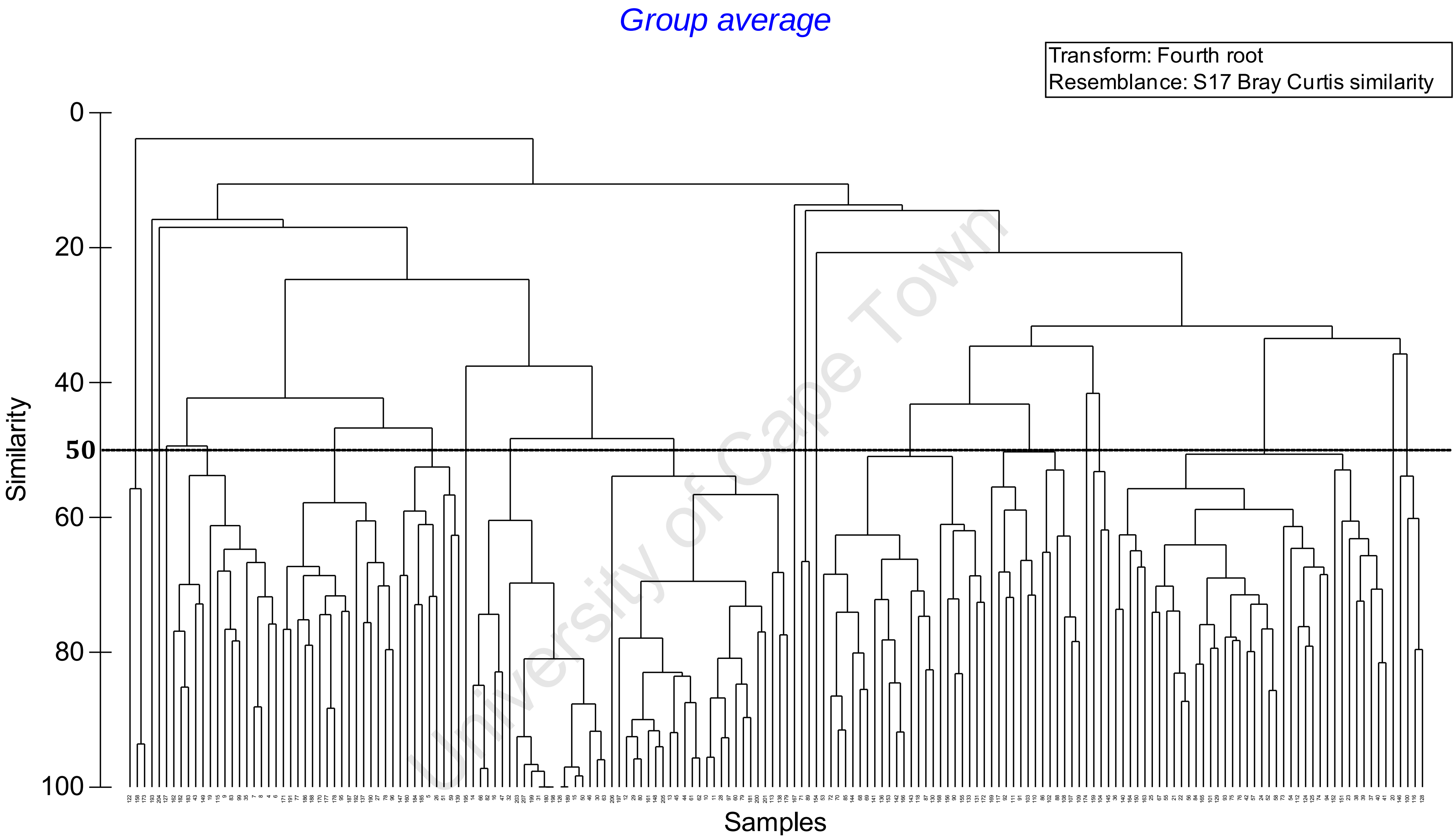

Figure 7: Cluster diagram showing similarity in biotopes among planning units

Table 6: Listing of PUs and biotopes for each cluster identified at 50% Bray Curtis similarity based on biotopes

Cluster	Planning Unit(s)	Average Similarity	Biotope(s)
a	122, 158, 173	68.34	Intertidal sand and mud
b	193		Fore reef corals and channels/shallow coastal
c	204		Ocean water
d	127		Sparse/moderate vegetation, moderate vegetation>1m, sparse coral blocks, consolidated limestone, deep coastal water, ocean water, waves and clouds
e	162, 182, 183, 43, 149, 19, 115, 9, 83, 99, 35, 7, 8, 4, 6	61.12	Deep coastal water and channels/shallow coastal
f	171, 191, 77, 186, 188, 170, 177, 178, 95, 187, 192, 137, 190, 27, 78, 96	63.49	Fore reef corals, channels/shallow coastal and dense corals
g	147, 160, 184, 185, 5, 26, 51, 59, 139	56.96	Sparse/moderate vegetation, consolidated limestone and moderate vegetation, shallow
h	195		Channels/shallow coastal, deep coastal and waves & clouds
i	14,66, 82, 16, 47, 32, 203, 207, 199, 31, 180, 198, 126, 189, 15, 50, 46, 30, 63	74.22	Deep coastal water
j	206, 197, 12, 29, 80, 161, 148, 205, 13, 45, 44, 61, 62, 10, 11, 28, 97, 60, 79, 181, 200, 201, 113, 138, 179	70.06	Deep coastal water and ocean water
k	167		Moderate/dense vegetation
l	71, 89	66.52	Sparse/ moderate vegetation
m	154		Sparse vegetation
n	53, 72, 70, 85, 144, 68, 69, 141, 136, 153, 142, 166, 143, 118, 156, 90, 155, 133, 131, 172	59.88	Sparse vegetation, dense vegetation and sparse/moderate vegetation
o	169, 117, 92, 111, 91, 103, 110, 86, 102, 88, 108, 107, 109	55	Dense vegetation, sparse vegetation and moderate vegetation/dark sediment
p	174		Sparse/moderate vegetation, dense corals, consolidated limestone, intertidal sand/mud and channels/shallow coastal
q	159, 104, 145	56.07	Sparse/moderate vegetation, intertidal sand/mud and moderate/dense vegetation
r	36, 140, 164, 150, 163, 25, 67, 55, 21, 22, 56, 84, 165, 101, 129, 93, 75, 76, 42, 57, 24, 52, 58, 73, 54, 112, 124, 125, 74, 94, 152, 151, 23, 38, 39, 37, 40, 41	57.97	Moderate vegetation > 1m, moderate vegetation and sparse vegetation > 1m
s	20		Sparse vegetation shallow, sparse vegetation>1m, sparse/moderate vegetation, reef edge corals, sparse coral blocks and consolidated limestone
t	146, 100, 116, 128	60.23	Moderate vegetation/shallow, sparse vegetation and sparse/moderate vegetation

2.3.2 Similarity of species composition in catches among planning units

At 45% similarity, 21 clusters of PUs were formed on the basis of similarity in catch composition. Table 7 below shows the different clusters formed, from left to right of figure 8, and the planning units along with the key fish species which contribute to each cluster formed, obtained from the SIMPER analysis. The average similarity between the planning units is also shown (Figure 8). Only the key fish species which contribute to each cluster formed are shown Table 7, whereas all fish species found in clusters containing only one planning unit were shown.

Cluster 'a' was a complete outlier and contained only the specie *Naso unicornis.*

The two major clusters, n and p, formed at 45% similarity contained planning units which are scattered in the lagoon or close to the reef barrier. *Caranx melampygus, Gerres longirostris, Lethrinus nebulosus, Siganus sutor* were abundant in both clusters. However, the average abundance of *Acanthurus triostegus*, *Mulloidichthys flavolineatus*, *Chlorurus sordidus* and *Naso unicornis* was higher in cluster 'n' than 'p', whereas the average abundance of *Valamugil seheli* and *Upeneus vittatus* is higher is cluster 'p' than 'n'.

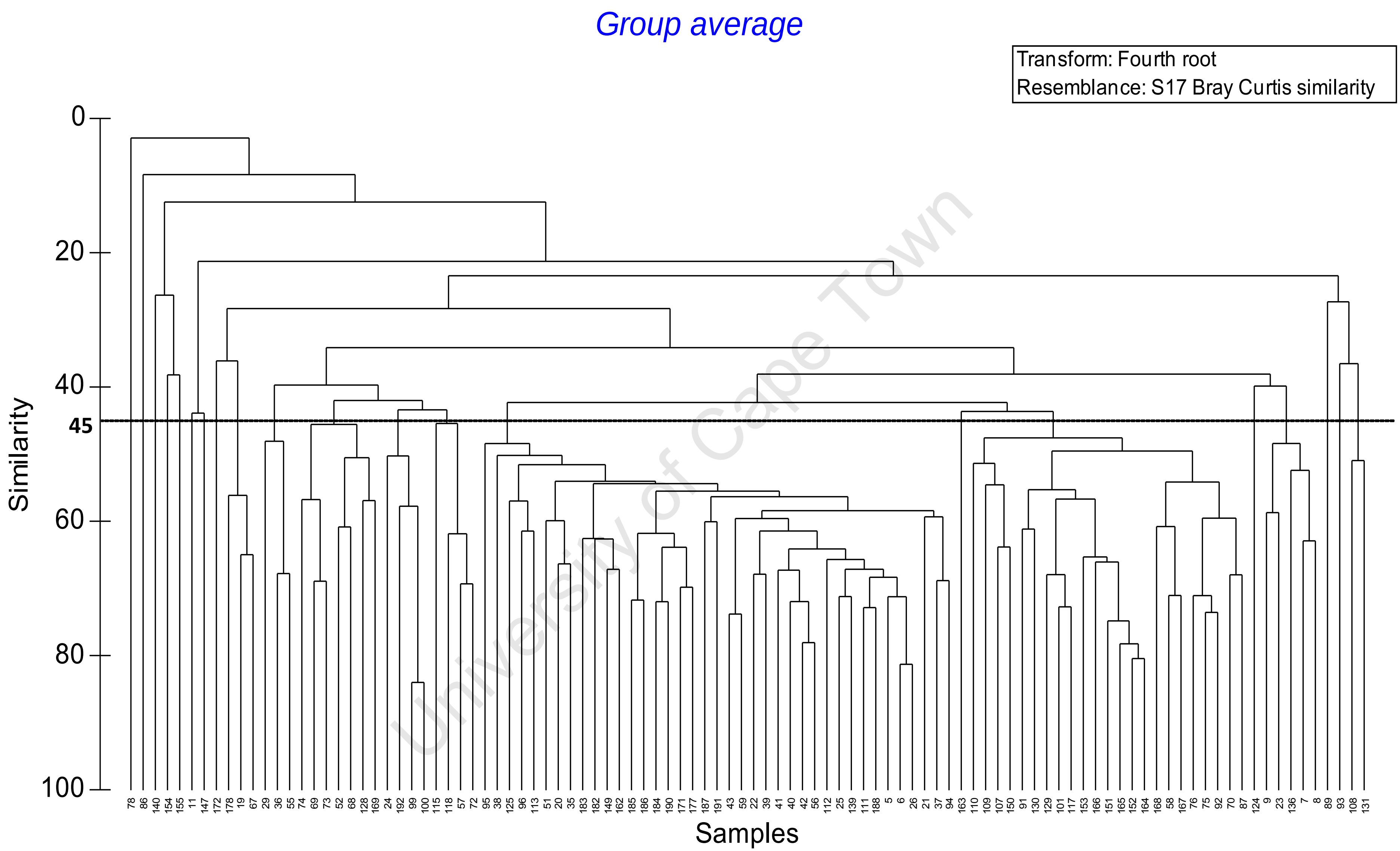

Figure 8: Cluster diagram showing similarity in species composition in catches among planning units

Table 7: Listing of PUs and fish species for each cluster identified at 50% Bray Curtis similarity based on fish catch

Cluster	Planning Unit(s)	Average similarity	Fish specie(s)
a	78		*Naso unicornis*
b	86		*Valamugil robustus, Caranx melampygus*
c	140		*Gerres longirostris*
d	154		*Mugil cephalus, Caranx papuensis, Chanos chanos, Gerres longirostris, Valagumil seheli*
e	155		*Valamugil robustus, Gerres longirostris, Caranx melampygus, Chanos chanos, Mugil cephalus, Uppeneus vittatus, Crenimugil crenilabis,*
f	11		*Acanthurus triostegus, Anampses caeruleopunctatus, Caranx melampygus, Lethrinus mahsena, Mulloidichthys vanicolensis, Chlorurus sordidus*
g	147		*Siganus sutor, Scarus specie, Lethrinus mahsena, Kyphosus cinerascens, Gerres longirostris, Chaetodon auriga, Caranx melampygus, Calotomus carolinus, Anampses caeruleopunctatus, Acanthurus triostegus*
h	172		*Lethrinus harak, Rhinecanthus aculeatus, Siganus sutor*
i	178, 19, 67	59.03	*Siganus sutor, Acanthurus triostegus, Chlorurus sordidus*
j	29, 36, 55	54.59	*Mulloidichthys flavolineatus, Lethrinus nebulosus, Siganus sutor*
k	74, 69, 73, 52, 68, 128, 169	49.90	*Siganus sutor, Gerres longirostris, Caranx melampygus*
l	12, 192, 99, 100	58.33	*Siganus sutor, Mulloidichthys flavolineatus, Caranx melampygus*
m	115, 118, 57, 72	54.84	*Siganus sutor, Lethrinus nebulosus, Caranx melampygus*
n	95, 38, 125, 96, 113, 51, 20, 35, 183, 182, 149, 162, 185, 186, 184, 190, 171, 177, 187, 191, 43, 59, 22, 39, 41, 40, 42, 56, 112, 25, 139, 111, 188, 5, 6, 26, 21, 37, 94	55.84	*Siganus sutor, Lethrinus nebulosus, Acanthurus triostegus, Caranx melampygus, Gerres longirostris, Mulloidichthys flavolineatus*
o	163		*Lethrinus nebulosis, Mugil cephalus, Siganus sutor, Gerres longirostris, Mulloidichthys vanicolensis, Parupeneus barberinus, Siganus argenteus, Leiognathus equulus, Parupeneus ciliatus*
p	110, 109, 107, 150, 91, 130, 129, 101, 117, 153, 166, 151, 165, 152, 164, 168, 58, 167, 76, 75, 92, 70, 87	52.46	*Siganus sutor, Caranx melampygus, Gerres longirostris, Lethrinus nebulosus, Mulloidichthys flavolineatus*
q	124		*Anampses caeruleopunctatus, Fistularia commersonii, Lethrinus mahsena, Lethrinus nebulosus, Mulloidichthys flavolineatus, Mulloidichthys vanicolensis, Rhinecanthus rectangulus, Siganus sutor, Siganus argenteus, Parupeneus rubescens, Tylosurus crocodiles, Chlorurus sordidus,*

			Parupeneus cyclostomus, Thalassoma trilobatum, Siganus luridus, Leptoscarus vaigiensis
r	9, 23, 136, 7, 8	51.63	*Lethrinus nebulosus, Siganus sutor, Scarus ghobban*
s	89		Few: *Gerres longirostris, Lethrinus nebulosus, Parupeneus barberinus, Siganus sutor, Sphyraena jello, Upeneus vittatus*
t	93		Abundant: *Mulloidichthys flavolineatus, Monodactylus argenteus* Few: *Caranx papuensis, Chanos chanos, Lethrinus nebulosus, Valamugil seheli*
u	108, 131	50.90	*Caranx papuensis, Valamugil seheli, Lethrinus nebulosus, Siganus sutor, Upeneus vittatus*

2.3.3 Linking the seine net fisheries data to the biotopes

The results from the Bio-Env test showed that most of the variation in fish species composition was explained by the extent of the following biotopes in each PU: vegetation, intertidal sand and mud, deep coastal water and ocean water. From reports by Shoals Rodrigues, sites close to the fringing reef and major channels and within coral areas were observed to be frequently targeted by the seine net fishing teams. Habitats within the fishing grounds included consolidated limestone, reef flat areas, seagrass/algae beds, sandy areas interspersed with coral blocks, coral patch reefs, reef edge corals and areas of dense coral. The planning units close to the fringing reef contained deep coastal water and ocean water in greater abundances than the reef edge, coral patch reef and dense corals (Appendix 7).

Table 8: Combinations of the 26 abiotic variables (biotope), taken k at a time, yielding the best matches of biotic and abiotic similarity matrices for each k

k	**Best variable combination**
1	Intertidal sand/mud(0.148), Ocean water(0.123), Dense vegetation(0.111)
2	Intertidal sand/mud, Ocean water (0.241), Intertidal sand/mud, Deep coastal water (0.215),Dense vegetation, Ocean water(0.190)
3	Moderate vegetation dark sediment, Intertidal sand/mud, Ocean water(0.254), Intertidal sand/mud, Deep coastal water, Ocean water(0.248), Dense vegetation, Intertidal sand/mud, Ocean water(0.248)
4	Moderate vegetation dark sediment, Intertidal sand/mud, Deep coastal water, Ocean water(0.276), Dense vegetation, Intertidal sand/mud, Deep coastal water, Ocean water(0.269), Moderate vegetation dark sediment, Channel edge corals, Intertidal sand/mud, Ocean water(0.245)
5	Moderate vegetation <1m, Moderate vegetation dark sediment, Intertidal sand/mud, Deep coastal water, Ocean water(0.279), Sparse/moderate vegetation <1m, moderate vegetation <1m, Intertidal sand/mud, Deep coastal water, Ocean water(0.269), Moderate vegetation dark sediment, Channels edge corals, Intertidal sand/mud, Deep coastal water, Ocean water(0.267)

2.3.4 Biotope data

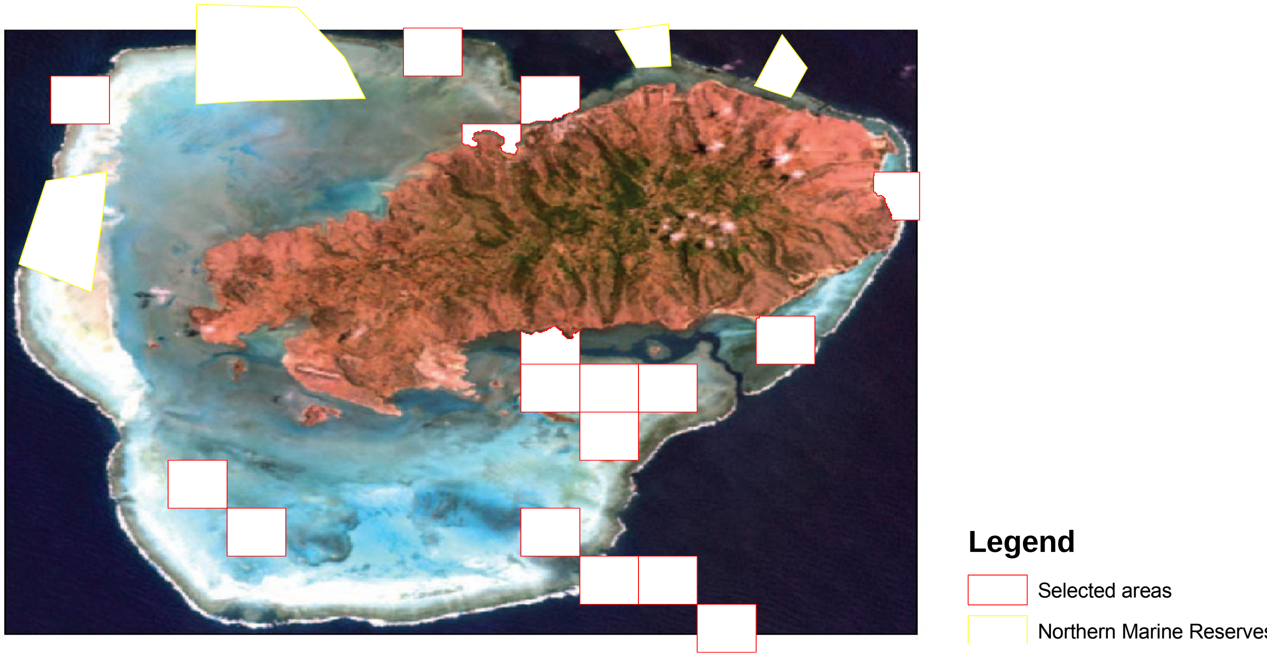

Figure 9: Planning units targeted using only biotope data

With 211 planning units, 26 conservation features and 480 boundaries, Marxan was run using only biotope data (Figure 9). A BLM of 0 was used and the SPF of some of the conservation features was calibrated so that all targets were met (Appendix 4). Red areas are areas which were selected by Marxan and yellow areas are the already established marine reserves.

The 17 planning units which were selected, which make up about 9% of the study region, contained the different biotopes in different abundances. Five planning units were selected in the north of the lagoon and 12 planning units in the south. Marxan proposed a selection of planning units which are close together and which cover all biotopes so that all targets were met. Seven of the planning units selected are found in cluster 'n' from the SIMPER analysis (Table 6), which contained sparse vegetation, dense vegetation, sparse/moderate vegetation, moderate/dense vegetation and intertidal sand/mud as key biotopes.

2.3.5 Seine Net Fisheries data

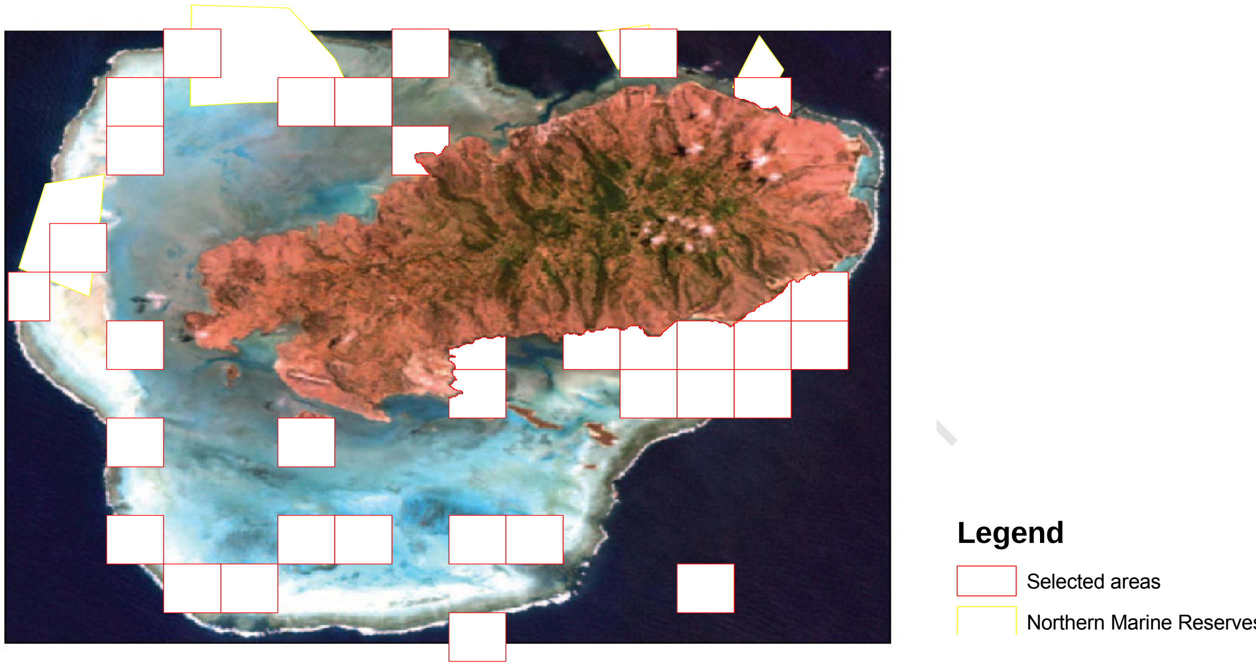

Figure 10: Planning units targeted using only seine net fisheries data

With 211 planning units, 118 conservation features and 480 boundaries, Marxan was run using only fishing effort data (Figure 10). A BLM of 0 was used and the SPF of some of the conservation features was calibrated so that most targets are met (Appendix 5). Thirty five planning units were selected for the reserve system, about 20% of the study region. The only targets not being met were *Scarus falcipinnis* and *Arothron immaculatus*; which were fished only one and twice respectively for seven years (Appendix 8). The areas selected represent the highest biodiversity of all the different fish species.

Seventeen of the planning units selected are found in cluster 'n' done in the SIMPER analysis (Table 7) for seine net fisheries data. The other planning units selected are found in most of the clusters where fish biodiversity was high.

2.3.6 Biotope and Seine Net Fisheries data

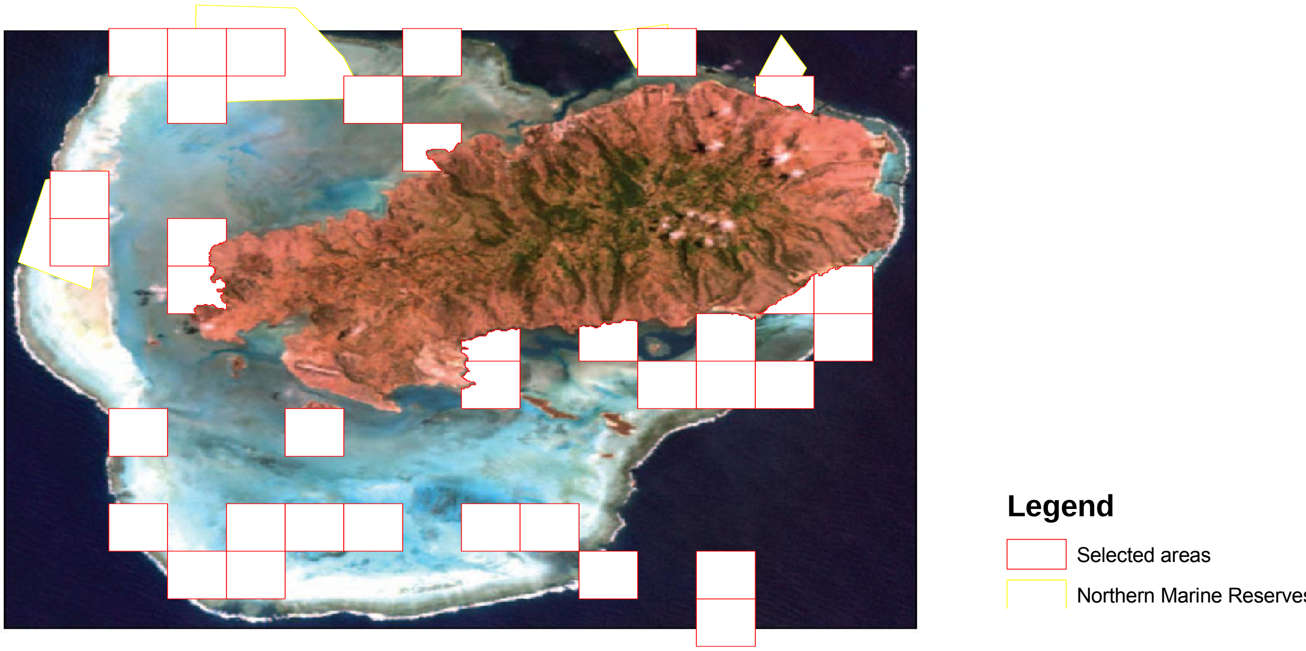

Figure 11: Planning units targeted using biotope & seine net fisheries data

Marxan was run using the biotope and seine net fishing data (Figure 11). A BLM of 0 and an SPF of 1 was used for all conservation features. The following targets were not met: *Scarus falcipinnis*, *Hyporhamphus affinis*, *Cantherhines pardalis*, *Ctenochaetus striatus*, *Zebrasoma veliferum*, *Selar crumenophthalmus*, *Acanthurus nigricans*, *Lethrinus xanthochilus*, *Mugil cephalus*, *Lethrinus spp*, *Caranx melampygus*, intertidal sand and mud, lagoon mud, coral path reef and sparse moderate vegetation <1m.

Out of 211 planning units, 36 were selected by Marxan as possible protected areas. This results in approximately 20% of the study region being selected as a protected area. Most are found near the reef or inside the lagoon with an exception of two planning units selected from outside the lagoon.

2.3.6.1 Calibration of Species Penalty Factor

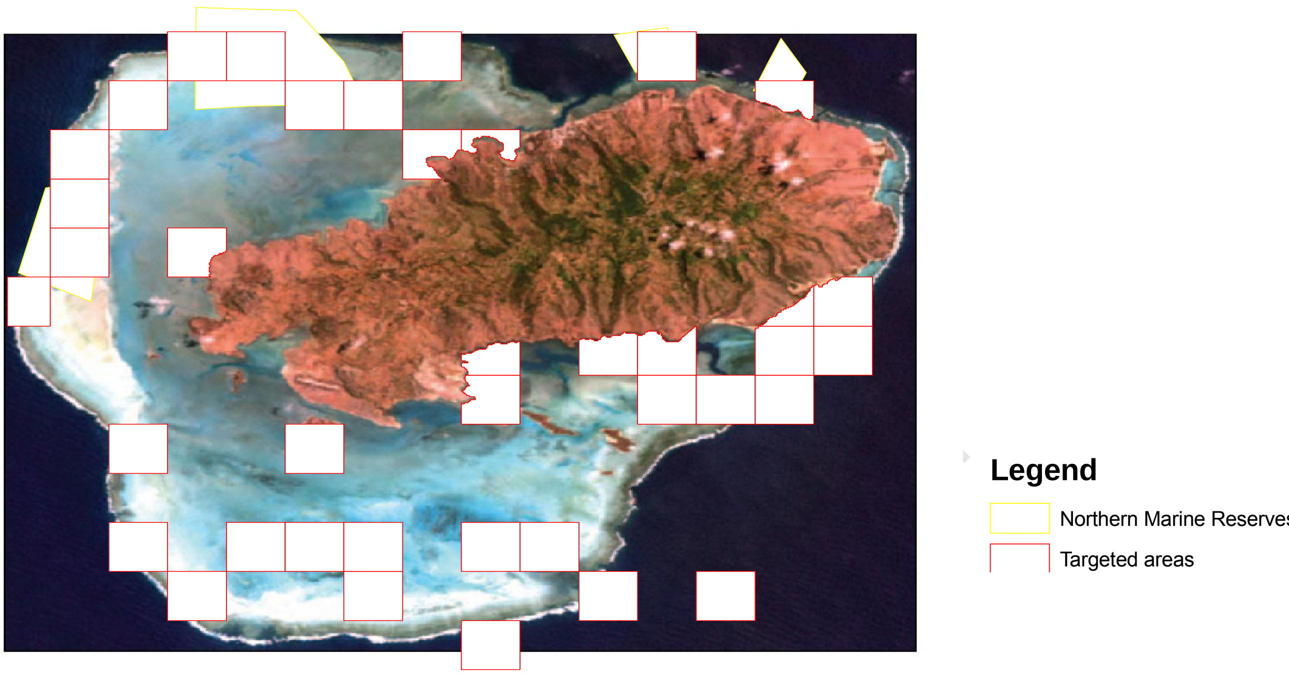

Figure 12: Targeted planning units when SPF is calibrated

In order to ensure that all conservation features are well represented in the reserve design, the SPF of conservation features for which targets were not met was increased (Appendix 6) so as to force them into the Marxan design. The scenario is different from the one proposed when an SPF of 1 was used (Figure 11). 39 areas were selected in this scenario, which makes up about 20% of the study region. The selected areas in the south part of the lagoon remain quite the same with some minor alterations however; more areas were selected in the north of the lagoon to incorporate all conservation features in the reserve design.

The only targets which were not met are *Scarus falcipinnis* and waves and clouds.

2.3.6.2 Locking in planning units containing marine reserves

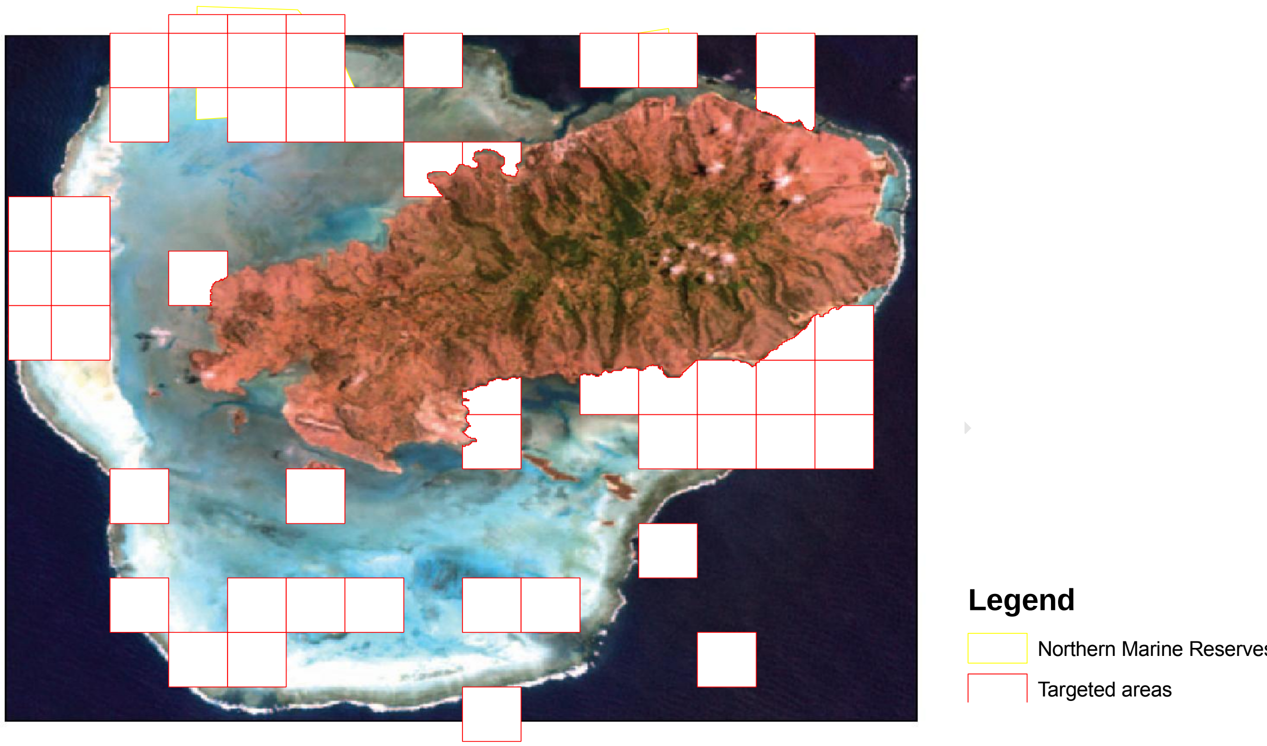

Figure 13: Targeted planning units when marine reserves are locked in

Marxan was run while locking in planning units which contained the established marine reserves and by setting the status of those planning units to a value 2 instead of 0 (Table 5). Therefore planning units with a status of 0 will be fixed in the reserve system.

The selected planning units remained practically the same with some minor changes in the south of the lagoon compared to the one produced when the status of planning units was 0 (Figure 12). In the north of the lagoon, planning units with a status of 2 remained fixed in the reserve design and planning units which were selected when the status was 0 for all them (Figure 12) were selected again in this scenario (Figure 13).

2.4 Discussion

2.4.1 Biotope

Chapman (2000) classified marine biotopes and produced a habitat map for the lagoon of Rodrigues. From the map, it was observed that the lagoon was mainly sand based, intermixed with rubble as well as occasional blocks of dead eroded coralline rock and occasional live coral. Moreover, there was little bare sand left uncovered throughout the lagoon due to sparse vegetation (algae and seagrass). Seagrass beds are uncommon (Chapman, 2000). Macroalgae are abundant, especially *Caulerpa* sp. (Turner & Klaus, 2005). Seagrass formed dense beds close to shore but was less abundant elsewhere in the lagoon while macroalgae has a patchy distribution, with occasional dense beds of *Caulerpa* sp. (Chapman, 2000). The coral reef system consists of the fringing reef, an extensive reef platform to the west, the reef flat towards the seaward edge and corals on channel walls (Turner & Klaus, 2005). Great variability was observed in coral distribution and morphology, reef community structure and reef-associated organisms within the lagoon, even at a very local scale (Foster, 2002; Ahamada *et al.*, 2004).

Living coral was the dominant biological group among the coral biotopes, followed by turf algae and then dead coral with algae and coralline algae (Foster, 2002). Where abundance of living coral was low, turf algae occurred in greater abundance and dead coral with algal cover was high in abundance. The endemic coral, *Acropora rodriguensis*, is common around the lagoon particularly on the reef flats (Hardman *et al.*, 2006). The greatest coral species richness in and around the lagoon is on the reef slopes, while lagoon habitats have the lowest species richness and low coral cover (Fenner *et al.*, 2004).

2.4.1.1 Cluster Analysis

The cluster analysis done on biotope data clearly showed two major clusters which were formed based on biotopes found in planning units close to the coral barrier and those found inside the lagoon. Planning units which were found close to the coral barrier contained deep coastal water, corals and ocean water as key biotopes whereas planning units which were found inside the lagoon were richer in vegetation. The difference in biotopes composition between those two groups explained why they clustered differently at 12% similarity.

The most abundant biotopes are sparse/moderate vegetation, sparse vegetation, deep coastal water, moderate/dense vegetation and moderate vegetation. Deep coastal water can be observed close to the coral barrier and vegetation is scattered inside the lagoon. Channel edge corals, lagoon mud, moderate vegetation – mud/basalt and sparse coral blocks are the scarcest biotopes.

2.4.1.2 Marxan Analysis

A possible explanation as to why more planning units were selected in the south compared to the north may be due to the fact that the south of the lagoon is much larger than the north and thus contains a larger abundance and variety of the different biotopes.

From the cluster analysis done, the planning units selected by Marxan were found in most of the clusters formed at 50% similarity. Therefore, a good representation of all the biotopes is being represented in the planning units selected by Marxan.

2.4.2 Seine net fishery

Shoals Rodrigues started monitoring the seine net fishery in 2002 and since then reports were made annually on the annual catch made. In 2008, no monitoring was done by the NGO due to a lack of staff and funding and in 2009 only the south of the island was monitored (Juangeer-Khan, pers. comm.). The fishery exploits multiple species, 118 fish were recorded from the total catch made in 2002 to 2009. However two species dominate the catch every year, *Siganus sutor* and *Mulloidichthys flavolineatus;* making up 48% of the total catch for eight years. The fishery is clearly dominated by herbivores and invertebrate feeders. The lack of predators clearly indicates some imbalance within the ecosystem, especially when taking into account that historically these species accounted for a much larger proportion of the catch (Pearson, 1988). Comparisons of catch statistics between 2002 and 2009 showed that there has been a change in species composition over the seven year period (Jhangeer-Khan *et al*., 2009). Surveys were done to assess the distribution of the two endemic fish species, *Pomacentrus rodriguesensis* and *Childichthys foudioides* (Hardman *et al*., 2006c). *C. foudioides* is rare around Rodrigues whereas *P. rodriguesensis* is common (Hardman *et al.*, 2006c).

2.4.2.1 Cluster Analysis

Twenty one clusters were formed at 45% similarity, indicating a high level of biodiversity across planning units. *Siganus sutor*, *Gerres longirostris* and *Mulloidichthys flavolineatus* were found in most of the clusters and they are also found among the four most caught fish species from 2002 to 2009. The two big clusters formed at 45% similarity contained a high abundance of the following species: *Siganus sutor, Mulloidichthys flavolineatus*, *Caranx melampygus, Gerres longirostris, Lethrinus nebulosus,*. A possible reason for this is that they are among the top six fish species caught; making them well scattered in various planning units in high abundances. The two clusters differ in their abundances of *Acanthurus triostegus* , *Mulloidichthys flavolineatus* and *Chlorurus sordidus*. Those species might be more abundant in particular regions; for instance *M. flavolineatus* is more abundant in the south *and A. triostegus* is more common near reef flat areas.

From the report done in 2007, *Siganus sutor* was more abundant on reef flat areas, *Mulloidichthys flavolineatus* was more dominant in the south on both the lagoon patch reefs and inshore sandy areas, and *Caranx melampygus* and *Gerres longirostris* were common in sandy lagoon areas in the south (Hardman *et al.*, 2008a). The cluster analysis showed that *S.sutor* was abundant close to the reefs and also in the south of the lagoon, *M. flavolineatus* is more dominant in the south, *C. melampygus* is also abundant close to the coral reef barrier and *G.longirostris* is caught mainly in sandy lagoon areas in the north and south of the island.

2.4.2.1 Marxan

The targets for *Scarus falcipinnis* and *Arothron immaculatus* were not met as their SPFs were not calibrated. Both fish were caught only once and twice respectively between 2002 and 2009 and increasing their SPFs would force them into the reserve design thus altering it (Game & Grantham, 2008). *Monodactylus argenteus,* was found only in the planning unit closest to the south of the island with a few rare species close by, making it of critical importance for the protection of this species.

More planning units were targeted in the south of the lagoon, possibly due to the fact that the south part is larger than the northern region and thus contains higher biodiversity and abundance.

From the cluster analysis done, the planning units selected by Marxan were found in most of the clusters formed at 45% similarity. Those particular clusters are those which contain the highest the number of different fish species; clearly showing that planning units which contained the highest biodiversity were selected.

2.4.3 Biotope & seine net fishery

The Bio-Env test was done to find which biotopes best explain the pattern in fish distribution. The expected results would have been areas containing biotopes high in dense corals, reef edge corals, fore reef corals and channel edge corals as species diversity is higher in regions rich in corals (Bellwood & Hughes, 2001). However, the results showed that regions high in vegetation, intertidal sand and mud, deep coastal water and ocean water were the biotopes which best explain the pattern in fish distribution. A possible reason for the results obtained is that planning units containing corals are found on the reef barrier and thus comprise deep coastal water and deep Ocean which are also in greater abundances. Moreover, there are seven biotopes containing corals; therefore the Bio-Env analysis linked fish with deep coastal water and ocean water instead of the different biotopes containing corals in smaller abundances; each coral type had less explanatory power (Clarke & Warwick, 2001). When more variables are used, 4 or 5, channels edge corals is incorporated into the main biotopes which best explain the pattern in fish distribution.

2.4.3.1 Marxan analysis

The planning units which were selected when using only biotope data are different to the planning units selected when only seine net fishery data were used. More planning units, twice as much than when only biotope data was used, were selected when only seine net fisheries data was used. A possible reason for this is that the number of conservation features for seine net fisheries data (118) is much higher than for biotope data (26). Therefore, more planning units were selected to protect all the different fish species.

The expected results for the Marxan scenario proposed when both biotope and seine net fishing data were used would be a combination of the results obtained when biotope and seine net fisheries data were used separately. Most areas which were selected when biotope and seine net fishing were used separately were selected in this scenario. The areas which were selected were along the reef barrier in the north of the lagoon and close to the reef barrier as well as channels in the south of the lagoon.

Calibrating the SPF to meet targets of all conservation features only changed the proposed reserve system slightly when all SPFs were set to one. The SPFs for waves and clouds and *Scarus falcipinnis* were not increased as waves and clouds vary and *S.falcipinnis* was caught only twice during a seven year period. If the SPFs of those conservation features were increased, this would force the solution to include those biotopes and thus will alter the scenario proposed.

2.4.4 Assessing the established marine reserves

It is unlikely that already established marine reserves will be traded for others. Therefore, the planning units containing the marine reserves were locked in into the reserve design and the results were compared to the precedent scenario. The planning units which were targeted when planning units were locked out were selected again when the planning units were locked in, clearly showing that the already established reserves are close in achieving the objectives set (Game & Grantham, 2008); without taking the south of the lagoon into consideration as the MPA(SEMPA) is still under construction. This validates the use of the stakeholder's knowledge to identify regions which require protection.

2.4.4.1 Anse Aux Anglais marine reserve

The marine reserve at Anse Aux Anglais was originally established to allow the area to recover from severe degradation from trampling to harvest octopus (Jacob, 2005) and also to promote tourism. Jacob (2005) observed that the west side of the marine reserve was badly damaged and suggested that the habitat is unproductive and will not recover. However, the east side of the reserve, which is inside the area selected by Marxan, flourishes with corals as the water is slightly deeper making it inaccessible to octopus fishers. From the GIS layer produced by Chapman (2004), fore coral reefs and some dense corals can be observed on the east and west sides of the marine reserve. From meetings held with stakeholders by Jacob (2005), most confirmed that the degradation of the west side is mainly due to octopus fishing, and surveys done showed more than 50% of the reef slopes are still in good condition.

From the SIMPER analysis done on biotope data, this region is rich in the following biotopes: fore reef corals, channels/shallow coastal, dense corals, consolidated limestone and reef edge corals. The SIMPER analysis done on seine net fisheries tells us that the site is rich in the following fish species: *Siganus sutor, Lethrinus nebulosus, Acanthurus triostegus, Caranx melampygus, Gerres longirostris and Mulloidichthys flavolineatus.* The six species are among the top ten commercially fished species. The site is, therefore, well placed as it contains commercially important fish species as well as important corals habitat. A possible scenario will be to increase the boundaries on the east side so as to cover the regions rich in live corals.

2.4.4.2 Riviere Banane marine reserve

The Riviere Banane marine reserve was selected mainly because it contains a special site known as the 'Aquarium'. This site is seen by fishers and scientists as a potential source of fish larvae and contains reef flat corals with recovery potential if protected (Gell, 2008). Moreover, the 'Aquarium' was identified as a distinct site both topographically and biologically combining a diversity of corals and fish, making it a popular tourist snorkeling site. It has been reported that corals on the reef slopes are still in good condition and that coral cover in the 'Aquarium' is high and comprises 69 coral species including the endemic coral *Acropora rodriguensis* as well as *Pomacentrus rodriguesensis,* a fish endemic to Mauritius and Rodrigues (Gell, 2008). Corals there were not affected by the recent bleaching event while those in the north and west sides of the island were affected (Hardman *et al*., 2004). The area was selected by Marxan thus indicating that it is a region of high biodiversity.

From SIMPER analysis done, the region is high in the following biotopes: fore reef corals, channels/shallow coastal, dense corals, consolidated limestone and reef edge corals; and the following fish species were abundant: *Siganus sutor, Lethrinus nebulosus, Acanthurus triostegus, Caranx melampygus, Gerres longirostris and Mulloidichthys flavolineatus.* The area contains several important commercial fish species as well as high biotope diversity.

2.4.4.3 Passe Demie marine reserve

The Passe Demie marine reserve is the least studied of the four marine reserves. Comparing the location of this reserve to the reserve system obtained from Marxan, Passe Demie fell mostly in the reserve system. When planning units containing existing marine reserves were locked in, the new reserve system clustered around the marine reserves and the targeted planning units in the precedent scenario. This marine reserve would be ideally placed if the boundaries are increased one mile north and south, aligning with the Marxan model.

From the SIMPER analysis done, the Passe Demie marine reserve is abundant in the following biotopes: sparse/moderate vegetation, moderate vegetation/shallow, deep coastal water, sparse coral blocks and dense corals. The following fish species are abundant in the reserve: *Siganus sutor, Lethrinus nebulosus, Acanthurus triostegus, Caranx melampygus, Gerres longirostris and Mulloidichthys flavolineatus.* The site is high in fish biodiversity and it also contains a variety of the different biotopes.

The Passe Demie marine reserve also comprises two islets which are bird sanctuaries and nature reserves. Ile Aaux Cocos, one of the islets, is also one of the main attractions of Rodrigues and provides major tourist revenue for the island's economy.

2.4.4.4 Grand Bassin marine reserve

The Grand Bassin marine reserve is the largest marine reserve north of the island with an area of 14.1 km^2, twice the size of Passe Demie and nine times larger than the other two. The reserve system proposed by Marxan lies inside the Grand Bassin marine reserve.

The endemic coral *Acropora rodriguensis* and endemic anemone fish *Amphirian chrysogaster* were recorded in this reserve along with shoals of juvenile fish particularly *Caranx melampygus* and *Naso unicornis* making it a potential nursery and spawning site (Winton, 2006; Hardman et al., 2006b). A telemetry fish tagging experiment found that *N. unicornis*, a bentho-pelagic species, remained within the reserve boundary for 57 days indicating the value of protection for important food fish such as this (Hardman *et al.,* 2010). Surveys carried out by Winton (2006) found a significant change in biotope cover than that identified by Chapman (2000). Coral cover had increased at 10.2% of sites and decreased at 17.5% while vegetation cover had increased at 49.8% of sites and decreased at 24.3%.

From the SIMPER analysis done, the area is abundant in the following biotopes: deep coastal water, moderate vegetation >1m, sparse vegetation, sparse/moderate vegetation, consolidated limestone and dense vegetation. The following fish species are abundant in the protected area: *Siganus sutor, Lethrinus nebulosus, Acanthurus triostegus, Caranx melampygus, Gerres longirostris, Mulloidichthys flavolineatus* and *Valamugil seheli.* The area contains a variety of biotopes and important commercial fish species.

From the results obtained, the boundaries of the marine reserves can be increased on the west and east side so as to cover more areas of high biodiversity thus protecting critical sites.

2.4.5 Which approach to use?

Setting up a marine reserve or a network of reserves is a tool which will help in preserving biodiversity and increase fish stocks in that particular area. However, all tools need to be used carefully, with an eye on its limitations. There is an on-going debate between the use of scientific or 'local' knowledge in selecting marine reserves (Chapin, 2004). In many cases, priority is given to one over the other and this has been attributed to the failure of some marine reserves. The need for a balance between these two aspects is of great importance for the success of marine reserves. However, achieving this balance is challenging. The complexity of 'local' knowledge makes it extremely difficult to manage. The main reason for this is that 'local' knowledge will vary from place to place and it will adapt and change with time. Thus, an appropriate approach is needed to manage the resources and to maintain sustainable fisheries.

The precautionary approach is essential for fisheries management in Rodrigues as data is limited and degradation is fast; there is a need for immediate action followed by adaptation when more data and information become available. The marine reserves will act as a tool for implementing the precautionary approach (Attwood, 1997). The MPAs will serve as a reservoir of biodiversity, protecting coral habitats and allowing fish stocks to recover (Hilborn *et al.*, 2004).Continuous monitoring within and outside the marine reserves will help scientists and other stakeholders on future decision making.

The total number of fish caught in Rodrigues between 2002 and 2009 amounted to approximately 83,419 individuals; of these 10,733 were caught in the already established marine reserves. Of the total catch during this period, 37,994 fish were caught in the areas proposed as protected areas from the Marxan analysis (when SPF was calibrated using biotype and seine net fisheries data). When the existing marine reserves and the proposed protected areas are combined the consequences for the fishery is apparent, approximately half the total catch (43,399 fish) caught in Rodrigues are caught in these protected areas. By reducing the fishing grounds through the designation of MPAs, fishermen lose out. Alternatives are needed for these fishermen so as to reduce their dependence on fishing, therefore allowing for recovery and time for the anticipated spillover effect to occur.

For the success of the marine reserves, a marine reserve network must be implemented to protect and allow the coral reefs to recover, support fish stocks through spill over of larval dispersion and adults and thus provide social and economic benefits. The marine reserves can also help coral reefs to recover from bleaching as has been shown in the Phoenix Island Protected area (Stone, 2010).

Chapter THREE

Chapter 3

Recommendations

A new biotope survey is needed to update the biotope layer since the 2000 layer did not distinguish between seagrass and algae but grouped them together as 'vegetation' (Winton, 2006). Moreover, there is significant change in biotope cover as stated earlier. Consistent monitoring of seine net fishing in the lagoon is also important for proper analysis and coverage. In 2008 no monitoring was done by Shoals Rodrigues due to a lack of funding and in 2009 only the south of island was monitored (Reshad Jhangeer-Khan, pers. comm.). The line fishers should also be monitored as they fish all year round compared to the seine net fishers which fish only from March to September. More research and surveys are needed to better understand the octopus fishery which should also be monitored as it is one of the most destructive practices to coral habitat.

More biological studies are required in the established marine reserves to determine critical spawning sites and dispersal of larvae and adult fish. Tagging studies on the most important fish species should also be carried to assess the effectiveness of the marine reserves.

Studies to differentiate biotic and abiotic factors between the north and south sides of the lagoon will also help in understanding the driving processes which sustain different habitats. Finally, further studies on the knowledge of local stakeholders should be done to incorporate this information into future planning initiatives.

Conclusions

The two main objectives for this project were attained. Regions of high marine biodiversity were identified in the lagoon and the effectiveness of the established marine reserves was assessed. This study found that the four current marine reserves adequately represent marine habitats in the lagoon and therefore meet the objectives even though the boundaries of all four reserves should be increased to maximise protection.

A network of marine reserves is important in the south of the island as there is extensive fishing and limited information on biological diversity between the north and the south sides of the lagoon. Moreover, the Marxan results strongly suggest protection in the south of the lagoon which is a region of high biodiversity and a locality for fish species not found in other parts of the lagoon. The proposed SEMPA MPA which is under development will provide the needed protection in the south of the island however will not cover all areas selected in the Marxan analysis.

The protection of biodiversity, mainly corals, is of primary importance as Rodrigues' corals have been referred as being the most developed and substantial in the Mascarenes (McClanahan *et al.*, 2000) and play an important role in carbon cycling (Fenner *et al.*, 2004; Payet, 2006). Marine reserves as a tool to protect natural reef habitats and increase fish stock seems appropriate for the island's small size and also as part of an integrated coastal zone management plan (Bunce *et al.,* 2008). A bottom-up approach to MPA establishment will allow greater stakeholder buy-in and possibly joint management and prevention of illegal harvesting. MPAs can be used to promote the importance of conservation through education and awareness initiatives. The precautionary approach provides some insurance for a small island whose inhabitants depend heavily on its natural resources but which is vulnerable to threats such as tsunamis, sea level rise and alien invasive species as well as the problem of limited resources and isolation from economic markets (Cicin-Sain, 1998). Coupled with adaptive management principles and decision-support tools such as Marxan, that allow for updating decisions based on new information, designing and managing MPAs to meet multiple objectives specific to conservation of biodiversity and enhancement of fisheries can be successfully achieved.

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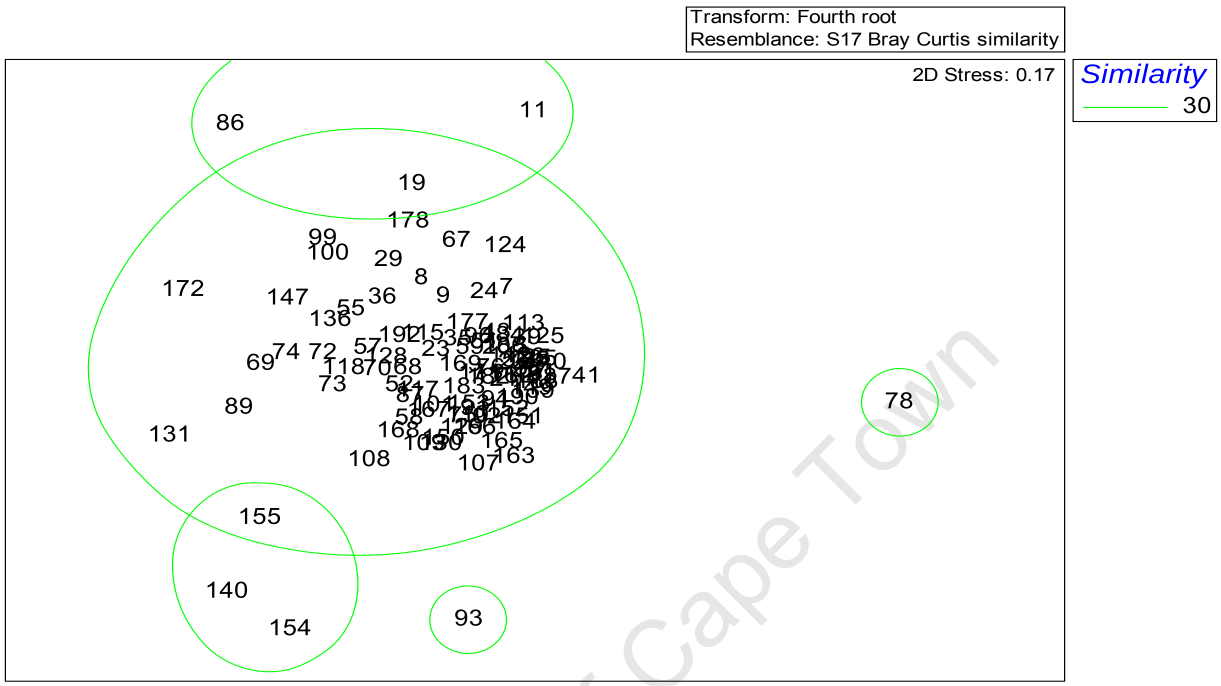
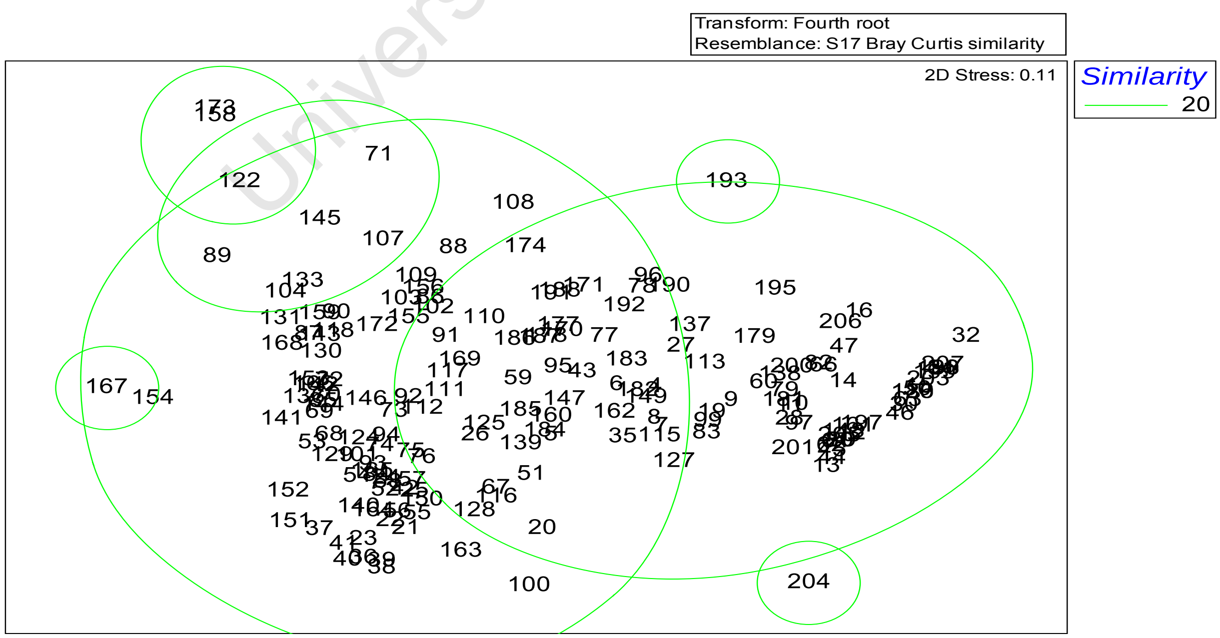
Appendices

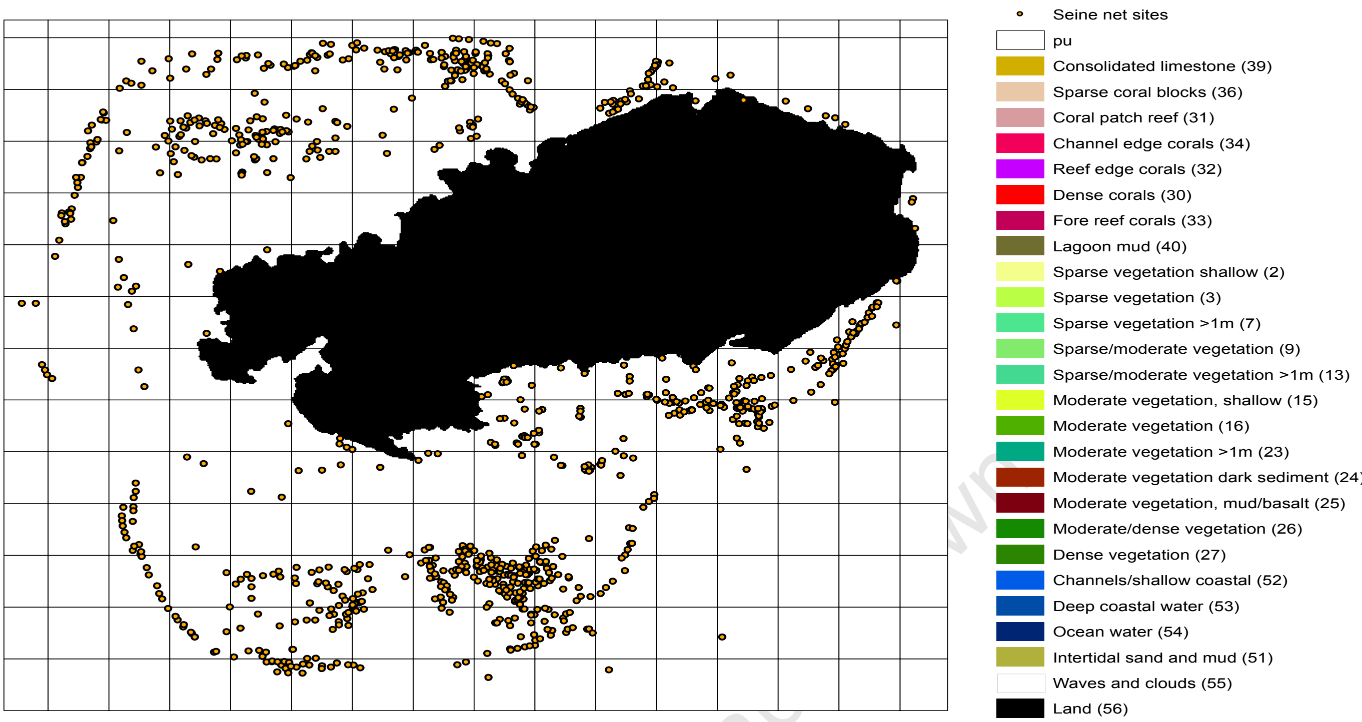
Appendix 1: Similarity between planning unit based on species composition in catches



Appendix 2: Similarity between planning unit based on biotope classification



Appendix 3: Seine net fishing sites within different biotopes



Appendix 4: Input parameter file

General Parameters
VERSION 0.1
BLM 0
PROP 5.00000000000000E-0001
RANDSEED -1
BESTSCORE 1.00000000000000E+0001
NUMREPS 100
Annealing Parameters
NUMITNS 1000000
STARTTEMP -1.00000000000000E+0000
COOLFAC 6.00000000000000E+0000
NUMTEMP 10000
Cost Threshold
COSTTHRESH 0.00000000000000E+0000
THRESHPEN1 1.40000000000000E+0001
THRESHPEN2 1.00000000000000E+0000

Appendix 5: SPF of conservation features for biotope data

Name	Target	SPF
Sparse vegetation shallow	145385.8	1
Sparse vegetation	816121.1	2
Sparse vegetation less than 1m	248659.1	3
Sparse/moderate vegetation	1005823	2
Sparse/moderate vegetation less than 1m	375700.6	3
Moderate vegetation shallow	302528.6	1
Moderate vegetation	651752.4	3
Moderate vegetation less than 1m	427008.3	3
Moderate vegetation dark sediment	85248.61	1
Moderate vegetation mud/basalt	51416.69	1
Moderate/ dense vegetation	740541.3	3
Dense vegetation	484058.1	4
Dense corals	429463.1	3
Coral path reef	123816.9	1
Reef edge corals	146605.4	1
Fore reef corals	254351.1	2
Channel edge corals	20220.31	1
Sparse coral blocks	72045.95	5
Consolidated limestone	261036.6	1
Lagoon mud	26268.14	2
Intertidal sand and mud	160962.5	2
Channels/ shallow coastal	466500.5	3
Deep coastal water	807584.1	6
Ocean water	327964.7	1
Waves and clouds	133562.5	1
land	163595.2	0

Appendix 6: SPF of conservation features for seine net fishing data

Name	Target	SPF
Siganus sutor	593.2982	1
Mulloidichthys flavolineatus	221.1682	1
Lethrinus nebulosus	233.7281	1
Gerres longirostris	146.6317	1
Caranx melampygus	168.3681	2
Acanthurus triostegus	152.4675	1
Valamugil seheli	49.73099	1
Mulloidichthys vanicolensis	33.15646	1
Siganus argenteus	27.17173	1
Naso unicornis	19.49714	1
Chlorurus sordidus	20.45022	1
Monodactylus argenteus	35.82172	1
Aluterus scriptus	0.08485	1
Anampses caeruleopunctatus	7.568583	1
Arothron stellatus	0.221289	2
Calotomus carolinus	0.134293	1
Carangoides orthogrammus	0.790966	1
Caranx papuensis	24.66538	3
Chaetodon auriga	0.184848	1
Chaetodon vagabundus	0.044545	1
Chanos chanos	6.391053	1
Cheilinus chlorourus	0.105237	1
Cheilinus trilobatus	3.928494	1
Epinephelus merra	0.008	2
Fistularia commersonii	4.037833	1
Hemiramphus far	1.425917	2
Kyphosus cinerascens	0.748946	1
Lethrinus harak	5.735555	1
Lethrinus mahsena	14.91815	1
Lethrinus spp	0.34	3
Mugil cephalus	64.49521	2
Naso tuberosus	0.310194	1
Parupeneus barberinus	8.796552	1
Rhinecanthus aculeatus	6.801757	1
Rhinecanthus rectangulus	0.614192	1
Scarus ghobban	7.793216	1
Scarus spp	6.24088	1
Scomberoides lysan	1.98177	1

Name	Target	SPF
Siganus rivulatus	17.25585	1
Parupeneus macronema	0.305362	1
Caranx sexfasciatus	0.06619	1
Acanthurus xanthopterus	0.05563	1
Acanthurus spp	19.75428	1
Lutjanus fulvus	0.701942	1
Monotaxis grandoculis	0.021053	1
Lethrinus xanthochilus	3.94251	2
Lethrinus lentjan	0.178793	1
Priacanthus blochii	0.010526	1
Pempheris vanicolensis	0.010526	1
Parupeneus rubescens	0.72245	1
Myripristis pralinia	7.063158	1
Gnathodentex aureolineatus	2.705781	1
Tylosurus crocodilus	1.040349	1
Sphyraena jello	9.749244	2
Hipposcarus harid	1.438928	1
Lethrinus olivaceus	0.139234	1
Upeneus vittatus	16.2429	2
Sargocentron diadema	0.010526	1
Leiognathus equulus	3.9194	1
Acanthurus nigricans	0.013464	2
Chaetodon trifasciatus	0.011765	1
Selar crumenophthalmus	0.428431	2
Coris aygula	0.47948	1
Parupeneus cyclostomus	0.561049	1
Acanthopagrus bifasciatus	0.024812	1
Gnathodentex speciosus	0.987302	2
Valamugil robustus	14.7	1
Crenimugil crenilabis	0.47746	1
Lethrinus rubrioperculatus	0.622613	1
Parupeneus ciliatus	7.088026	1
Chaetodon xanthocephalus	0.059951	1
Scarus scaber	0.080924	1
Chlorurus strongylocephalus	0.029219	1
Scarus psittacus	4.179407	1
Lutjanus kasmira	0.131111	2
Rhabdosargus sarba	3.141937	1
Gomphosus caeruleus	0.054545	1

Name	**Target**	**SPF**
Naso brachycentron	0.122332	1
Zebrasoma veliferum	0.24881	2
Ctenochaetus striatus	1.766682	2
Chaetodon zanzibarensis	0.15	1
Cheilio inermis	0.097734	1
Hemigymnus fasciatus	0.342606	1
Thalassoma quinquevittatum	0.05	1
Parupeneus trifasciatus	0.327601	1
Albula glossodonta	0.883193	1
Anampses meleagrides	0.008696	1
Scarus viridifucatus	0.035556	1
Bolbometopon muricatum	0.004444	1
Novaculichthys taeniourus	0.10303	1
Elops machnata	0.625	1
Acanthurus mata	0.207005	1
Cantherhines pardalis	0.142029	2
Myripristis berndti	2.2	1
Scarus globiceps	0.095652	1
Sphyraena flavicauda	2.64	1
Hyporhamphus affinis	0.34	5
Leptomelanosoma indicum	0.08	1
Trachinotus baillonii	0.02	1
Sphyraena barracuda	0.016471	1
Thalassoma trilobatum	0.358788	1
Epinephelus spilotoceps	0.004545	1
Halichoeres scapularis	0.031515	1
Amanses scopas	0.006897	2
Acanthurus nigrofuscus	0.808586	1
Scarus falcipinnis	0.011877	1
Arothron immaculatus	0.014286	1
Siganus luridus	0.743575	1
Lutjanus bohar	0.02	1
Coris cuvieri	0.066667	1
Scarus rubroviolaceus	0.008889	1
Diodon spp	0.013333	1
Hologymnosus longibes	0.018182	1
Aprion virescens	0.025	1
Cantherines dumerilii	0.004545	1
Leptoscarus vaigiensis	0.225657	1

Name	Target	SPF
Thalassoma hardwicke	0.2	1
Sphyraena obtusata	0.094737	1

Appendix 7: SPF of all conservation features for biotope and seine net fishing

Name	Target	SPF
Sparse vegetation shallow	145385.8	6
Sparse vegetation	816121.1	1
Sparse vegetation less than 1m	248659.1	1
Sparse/moderate vegetation	1005823	1
Sparse/moderate vegetation less than 1m	375700.6	4
Moderate vegetation shallow	302528.6	2
Moderate vegetation	651752.4	1
Moderate vegetation less than 1m	427008.3	1
Moderate vegetation dark sediment	85248.61	1
Moderate vegetation mud/basalt	51416.69	1
Moderate/ dense vegetation	740541.3	2
Dense vegetation	484058.1	1
Dense corals	429463.1	1
Coral path reef	123816.9	2
Reef edge corals	146605.4	1
Fore reef corals	254351.1	1
Channel edge corals	20220.31	1
Sparse coral blocks	72045.95	1
Consolidated limestone	261036.6	1
Lagoon mud	26268.14	2
Intertidal sand and mud	160962.5	2
Channels/ shallow coastal	466500.5	1
Deep coastal water	807584.1	1
Ocean water	327964.7	2
Waves and clouds	133562.5	1
land	163595.2	1
Siganus sutor	593.2982	1
Mulloidichthys flavolineatus	221.1682	1
Lethrinus nebulosus	233.7281	1
Gerres longirostris	146.6317	1
Caranx melampygus	168.3681	2
Acanthurus triostegus	152.4675	1

Name	Target	SPF
Valamugil seheli	49.73099	1
Mulloidichthys vanicolensis	33.15646	1
Siganus argenteus	27.17173	1
Naso unicornis	19.49714	1
Chlorurus sordidus	20.45022	1
Monodactylus argenteus	35.82172	1
Aluterus scriptus	0.08485	1
Anampses caeruleopunctatus	7.568583	1
Arothron stellatus	0.221289	2
Calotomus carolinus	0.134293	1
Carangoides orthogrammus	0.790966	1
Caranx papuensis	24.66538	3
Chaetodon auriga	0.184848	1
Chaetodon vagabundus	0.044545	1
Chanos chanos	6.391053	1
Cheilinus chlorourus	0.105237	1
Cheilinus trilobatus	3.928494	1
Epinephelus merra	0.008	1
Fistularia commersonii	4.037833	1
Hemiramphus far	1.425917	2
Kyphosus cinerascens	0.748946	1
Lethrinus harak	5.735555	1
Lethrinus mahsena	14.91815	1
Lethrinus spp	0.34	2
Mugil cephalus	64.49521	2
Naso tuberosus	0.310194	1
Parupeneus barberinus	8.796552	1
Rhinecanthus aculeatus	6.801757	1
Rhinecanthus rectangulus	0.614192	1
Scarus ghobban	7.793216	1
Scarus spp	6.24088	1
Scomberoides lysan	1.98177	1
Siganus rivulatus	17.25585	1
Parupeneus macronema	0.305362	1
Caranx sexfasciatus	0.06619	1
Acanthurus xanthopterus	0.05563	1
Acanthurus spp	19.75428	1
Lutjanus fulvus	0.701942	1
Monotaxis grandoculis	0.021053	1

Name	Target	SPF
Lethrinus xanthochilus	3.94251	2
Lethrinus lentjan	0.178793	1
Priacanthus blochii	0.010526	1
Pempheris vanicolensis	0.010526	1
Parupeneus rubescens	0.72245	1
Myripristis pralinia	7.063158	1
Gnathodentex aureolineatus	2.705781	1
Tylosurus crocodilus	1.040349	1
Sphyraena jello	9.749244	2
Hipposcarus harid	1.438928	1
Lethrinus olivaceus	0.139234	1
Upeneus vittatus	16.2429	2
Sargocentron diadema	0.010526	1
Leiognathus equulus	3.9194	1
Acanthurus nigricans	0.013464	2
Chaetodon trifasciatus	0.011765	1
Selar crumenophthalmus	0.428431	2
Coris aygula	0.47948	1
Parupeneus cyclostomus	0.561049	1
Acanthopagrus bifasciatus	0.024812	1
Gnathodentex speciosus	0.987302	2
Valamugil robustus	14.7	1
Crenimugil crenilabis	0.47746	1
Lethrinus rubrioperculatus	0.622613	1
Parupeneus ciliatus	7.088026	1
Chaetodon xanthocephalus	0.059951	1
Scarus scaber	0.080924	1
Chlorurus strongylocephalus	0.029219	1
Scarus psittacus	4.179407	1
Lutjanus kasmira	0.131111	1
Rhabdosargus sarba	3.141937	1
Gomphosus caeruleus	0.054545	1
Naso brachycentron	0.122332	1
Zebrasoma veliferum	0.24881	2
Ctenochaetus striatus	1.766682	2
Chaetodon zanzibarensis	0.15	1
Cheilio inermis	0.097734	1
Hemigymnus fasciatus	0.342606	1
Thalassoma quinquevittatum	0.05	1

Name	**Target**	**SPF**
Parupeneus trifasciatus	0.327601	1
Albula glossodonta	0.883193	1
Anampses meleagrides	0.008696	1
Scarus viridifucatus	0.035556	1
Bolbometopon muricatum	0.004444	1
Novaculichthys taeniourus	0.10303	1
Elops machnata	0.625	1
Acanthurus mata	0.207005	1
Cantherhines pardalis	0.142029	2
Myripristis berndti	2.2	1
Scarus globiceps	0.095652	1
Sphyraena flavicauda	2.64	1
Hyporhamphus affinis	0.34	4
Leptomelanosoma indicum	0.08	1
Trachinotus baillonii	0.02	1
Sphyraena barracuda	0.016471	1
Thalassoma trilobatum	0.358788	1
Epinephelus spilotoceps	0.004545	1
Halichoeres scapularis	0.031515	1
Amanses scopas	0.006897	1
Acanthurus nigrofuscus	0.808586	1
Scarus falcipinnis	0.011877	2
Arothron immaculatus	0.014286	1
Siganus luridus	0.743575	1
Lutjanus bohar	0.02	1
Coris cuvieri	0.066667	1
Scarus rubroviolaceus	0.008889	1
Diodon spp	0.013333	1
Hologymnosus longibes	0.018182	1
Aprion virescens	0.025	1
Cantherines dumerilii	0.004545	1
Leptoscarus vaigiensis	0.225657	1
Thalassoma hardwicke	0.2	1
Sphyraena obtusata	0.094737	1

Appendix 8: Habitat and feeding information for 12 most fished species

Fish Species	**Feeding type**	**Habitat**
Siganus sutor	Herbivore	Inhabits inshore areas and inner reefs / Often occurs among seagrasses
Mulloidichthys flavolineatus	Invertebrate feeder	Schooling species inhabit shallow sandy areas of lagoon and seaward reefs / Benthopelagic
Lethrinus nebulosus	Invertebrate feeder	Inhabit coral reefs, coralline lagoons, seagrass beds, mangrove swamps and coastal sand and rock areas
Gerres longirostris	Invertebrate feeder	Prefers shallow waters over sandy bottoms
Caranx melampygus	Piscivore	A coastal and oceanic species, associated with reefs
Acanthurus triostegus	Herbivore	Occur in lagoon and seaward reefs with hard substrate; young abundant in tide pools / Benthopelagic
Valamugil seheli	Invertebrate feeder	Inhabit coastal waters but enters estuaries and rivers to feed
Mulloidichthys vanicolensis	Invertebrate feeder	Inhabits sandy bottoms of reef flats, lagoons, and seaward reefs / Benthopelagic
Siganus argenteus	Herbivore	Inhabits coastal and inner reef slopes and lagoons
Naso unicornis	Herbivore	Inhabit channels, moats, lagoon and seaward reefs with strong surge / Benthopelagic
Chlorurus sordidus	Herbivore	Inhabit both coral rich and areas of shallow reef flats and lagoon and seaward reefs / Benthopelagic
Monodactylus argenteus	Detrivore	Occasionally in silty coastal reefs

Appendix 9: List of all fish species & catch from 2002 to 2009

Fish species	Rank	Catch	Cumulative catch	cumulative species
Siganus sutor	1	27781	27781	0.333029646
Mulloidichthys flavolineatus	2	12337	40118	0.480921613
Lethrinus nebulosus	3	8152	48270	0.578645153
Gerres longirostris	4	5937	54207	0.649815989
Caranx melampygus	5	5406	59613	0.714621369
Acanthurus triostegus	6	5100	64713	0.77575852
Valamugil seheli	7	2328	67041	0.803665832
Mulloidichthys vanicolensis	8	1717	68758	0.824248672
Siganus argenteus	9	1270	70028	0.839473022
Naso unicornis	10	1262	71290	0.85460147
Chlorurus sordidus	11	1251	72541	0.869598053
Monodactylus argenteus	12	1120	73661	0.883024251
Acanthurus spp	13	833	74494	0.893009986
Upeneus vittatus	14	744	75238	0.901928817
Myripristis pralinia	15	676	75914	0.910032487
Mugil cephalus	16	659	76573	0.917932366
Siganus rivulatus	17	583	77156	0.924921181
Sphyraena jello	18	495	77651	0.930855081
Lethrinus mahsena	19	477	78128	0.936573203
Rhinecanthus aculeatus	20	424	78552	0.941655978
Lethrinus harak	21	402	78954	0.946475024
Scarus ghobban	22	394	79348	0.951198168
Caranx papuensis	23	353	79701	0.955429818
Parupeneus barberinus	24	293	79994	0.958942207
Leiognathus equulus	25	240	80234	0.96181925
Anampses caeruleopunctatus	26	217	80451	0.964420576
Scarus spp	27	207	80658	0.966902025
Ctenochaetus striatus	28	180	80838	0.969059807
Parupeneus ciliatus	29	163	81001	0.971013798
Acanthurus nigrofuscus	30	152	81153	0.972835925
Valamugil robustus	31	145	81298	0.974574138
Rhabdosargus sarba	32	141	81439	0.9762644
Chanos chanos	33	138	81577	0.9779187
Sphyraena flavicauda	34	132	81709	0.979501073
Scarus psittacus	35	130	81839	0.981059471
Hipposcarus harid	36	128	81967	0.982593893
Cheilinus trilobatus	37	119	82086	0.984020427
Hemiramphus far	38	107	82193	0.985303108
Scomberoides lysan	39	101	82294	0.986513864
Fistularia commersonii	40	91	82385	0.987604742
Lethrinus xanthochilus	41	86	82471	0.988635683
Gnathodentex aureolineatus	42	70	82541	0.98947482
Kyphosus cinerascens	43	62	82603	0.990218056
Albula glossodonta	44	56	82659	0.990889366

Fish species	**Rank**	**Catch**	**Cumulative catch**	**cumulative species**
Tylosurus crocodilus	45	53	82712	0.991524713
Lutjanus fulvus	46	43	82755	0.992040183
Parupeneus rubescens	47	38	82793	0.992495714
Naso tuberosus	48	36	82829	0.992927271
Carangoides orthogrammus	49	34	82863	0.993334852
Selar crumenophthalmus	50	34	82897	0.993742433
Gnathodentex speciosus	51	28	82925	0.994078088
Acanthurus mata	52	24	82949	0.994365792
Coris aygula	53	24	82973	0.994653496
Myripristis berndti	54	22	82995	0.994917225
Parupeneus cyclostomus	55	22	83017	0.995180954
Lethrinus olivaceus	56	20	83037	0.995420708
Siganus luridus	57	20	83057	0.995660461
Lethrinus rubrioperculatus	58	19	83076	0.995888227
Rhinecanthus rectangulus	59	19	83095	0.996115993
Hyporhamphus affinis	60	17	83112	0.996319783
Parupeneus trifasciatus	61	16	83128	0.996511586
Cheilinus chlorourus	62	15	83143	0.996691401
Crenimugil crenilabis	63	15	83158	0.996871216
Lethrinus lentjan	64	15	83173	0.997051032
Scarus scaber	65	14	83187	0.997218859
Cheilio inermis	66	13	83200	0.997374699
Thalassoma trilobatum	67	13	83213	0.997530539
Hemigymnus fasciatus	68	11	83224	0.997662403
Scarus globiceps	69	11	83235	0.997794267
Elops machnata	70	10	83245	0.997914144
Chaetodon auriga	71	9	83254	0.998022033
Sphyraena obtusata	72	9	83263	0.998129922
Parupeneus macronema	73	8	83271	0.998225824
Scarus viridifucatus	74	8	83279	0.998321725
Naso brachycentron	75	7	83286	0.998405639
Novaculichthys taeniourus	76	7	83293	0.998489553
Sphyraena barracuda	77	7	83300	0.998573466
Chaetodon melannotus	78	6	83306	0.998645393
Chlorurus strongylocephalus	79	6	83312	0.998717319
Lutjanus kasmira	80	6	83318	0.998789245
Acanthurus xanthopterus	81	5	83323	0.998849183
Aluterus scriptus	82	5	83328	0.998909121
Calotomus carolinus	83	5	83333	0.99896906
Lethrinus spp	84	5	83338	0.999028998
Zebrasoma veliferum	85	5	83343	0.999088937
Caranx sexfasciatus	86	4	83347	0.999136887
Chaetodon xanthocephalus	87	4	83351	0.999184838
Leptomelanosoma indicum	88	4	83355	0.999232789
Leptoscarus vaigiensis	89	4	83359	0.999280739
Arothron stellatus	90	3	83362	0.999316702

Fish species	**Rank**	**Catch**	**Cumulative catch**	**cumulative species**
Cantherhines pardalis	91	3	83365	0.999352665
Cantherines dumerilii	92	3	83368	0.999388628
Chaetodon vagabundus	93	3	83371	0.999424592
Diodon spp	94	3	83374	0.999460555
Halichoeres scapularis	95	3	83377	0.999496518
Monotaxis grandoculis	96	3	83380	0.999532481
Acanthopagrus bifasciatus	97	2	83382	0.999556456
Acanthurus nigricans	98	2	83384	0.999580431
Chaetodon zanzibarensis	99	2	83386	0.999604407
Chlorurus oedema	100	2	83388	0.999628382
Coris cuvieri	101	2	83390	0.999652357
Gomphosus caeruleus	102	2	83392	0.999676333
Scarus falcipinnis	103	2	83394	0.999700308
Scarus rubroviolaceus	104	2	83396	0.999724283
Trachinotus blochii	105	2	83398	0.999748259
Abudefduf sexfasciatus	106	1	83399	0.999760246
Amanses scopas	107	1	83400	0.999772234
Anampses meleagrides	108	1	83401	0.999784222
Aprion virescens	109	1	83402	0.999796209
Arothron immaculatus	110	1	83403	0.999808197
Bolbometopon muricatum	111	1	83404	0.999820185
Carangoides ferdau	112	1	83405	0.999832173
Chaetodon trifasciatus	113	1	83406	0.99984416
Epinephelus merra	114	1	83407	0.999856148
Epinephelus spilotoceps	115	1	83408	0.999868136
Hologymnosus longibes	116	1	83409	0.999880123
Lutjanus bohar	117	1	83410	0.999892111
Pempheris vanicolensis	118	1	83411	0.999904099
Priacanthus blochii	119	1	83412	0.999916086
Sargocentron diadema	120	1	83413	0.999928074
Scarus frenatus	121	1	83414	0.999940062
Stegastes limbatus	122	1	83415	0.999952049
Thalassoma genivittatum	123	1	83416	0.999964037
Thalassoma hardwicke	124	1	83417	0.999976025
Thalassoma quinquevittatum	125	1	83418	0.999988012
Trachinotus baillonii	126	1	83419	1

Appendix 10: Types of fishing activities in Rodrigues

Plate 1: seine net fishers

Plate 2: basket trap

Plate 3: octopus fisher